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Using Kinesthetics for Actively Learning Science (KALS)

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ABSTRACT

Body movement and exercise (kinesthetics) have been used to teach a variety of abstract science content. In this paper, we provide an introductory “one stop shop” summary and review on a variety of Kinesthetics for Actively Learning Science (KALS), ranging from simply rubbing hands together to demonstrate friction to choreographing the life cycle of stars. To assist science educators in implementing KALS, we compiled a ready to use list of KALS in a tabular format and references. In this table we 1) align KALS with Next Generation Science Standards (NGSS) and rate KALS for their ease of implementation. The most common KALS in our sample were activities relating to the earth sciences, followed by the physical and life sciences, evenly split between the middle and high school standards. KALS were divided equally between activities that could easily be implemented in the classroom and those requiring more planning. We conclude our review with practical tips for successfully implementing KALS in any classroom.

INTRODUCTION

Body movement and exercise have been used to teach abstract science content relating to brain function, meiosis – mitosis, star evolution, plate tectonics, and much more. The only real “equipment” needed to demonstrate science concepts is students’ own bodies.

Eye opening and exciting, Kinesthetics for Actively Learning Science (KALS) can be a memorable experience for students sometimes dulled by an over reliance on lecture, workbook exercises, and canned experiments.

Our experience suggests that KALS inspire students to learn and this is supported in the research literature (Reinfeld & Hartman, 2008; Chinnici et al. 2004). We have also discovered that some teachers are unaware how KALS can be used to teach science. Even if familiar with KALS, teachers may not have the time to access useful activities spread across a wide variety of books, journals, and the web. To address these issues, we compiled a ready to go list of KALS (and references) for a variety of science concepts. In this table we: 1) align KALS with NGSS and 2) rate KALS for their ease of implementation. We conclude with practical tips for successfully implementing KALS.

METHODS

In compiling KALS, we considered the most reliable sources, those appearing in the peer reviewed literature. We also, however, include KALS that were anecdotal or discovered on the web, not yet formally reviewed. We assigned KALS to NGSS based on stated learning objectives in the article. In rating how easily KALS could be incorporated into lessons, we used “Less Planning” (LP) and “More Planning” (MP) categories. KALS(LP) involved few directions needed to complete the activity, did not require props (like signs), and usually featured...
students sitting or standing in place. KALS(LP) also have reduced chance of injury due to student collisions and are better able to accommodate students with disabilities. KALS(MP) generally have more elaborate instructions, can include props, contain more complex movements with multiple student roles, and require more space. Such activities could also, because of their more involved procedure, discourage participation by students with disabilities.

The 16Life Cycle of StarsMP listing in Table 1, for example, is authored by Reinfeld & Hartman (superscript15), would require more planning MP, and is appropriate for the NGSS “Space Systems” performance expectations. This is followed by the “Activity Description.” Space limitations prevent a detailed description of each KAL; we provide, however, a brief summary. The following Science and Engineering Practices and Cross Cutting Concepts are supported by KALs:

**Science and Engineering Practices:**
- Developing and Using Models
- Constructing Explanations
- Engaging in Argument from Evidence

**Cross-cutting Concepts:**
- Cause and Effect and Patterns.
- Systems and System Models
- Scale, Proportion and Quantity
- Energy and Matter
- Stability and Change

Consult NGSS documentation (ngss.org) to find which specific Practice(s) or Concept(s) are best illustrated by each Disciplinary Core Idea (DCI). To obtain a more thorough description of the KALS, consult the reference.
### TABLE 1. KALS ORGANIZED BY SUBJECT, CONCEPT, AND NGSS.

<table>
<thead>
<tr>
<th>KAL Concept</th>
<th>NGSS</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle of Stars&lt;sup&gt;MP&lt;/sup&gt;</td>
<td>HS-ESS1</td>
<td>Students spread out as particles located in the star's envelope/core; then by moving to set locations, depict star progression through nebula, protostar, main sequence, and red giant. The KAL concludes with two types of “deaths”: nebula and supernova.</td>
</tr>
<tr>
<td>Stellar and Planetary Motion&lt;sup&gt;MP&lt;/sup&gt;</td>
<td>HS-ESS1</td>
<td>Parallax, Ptolemaic motion, and Copernican motion are demonstrated. Students act as moving/non-moving planets, fixed stars, epicenters, and moons. In parallax, for instance, students line up in pairs, with one line of students moving to the right and observing how their partner’s head (representing a planet) appears to move against the background.</td>
</tr>
<tr>
<td>Plate Tectonics&lt;sup&gt;LP&lt;/sup&gt;</td>
<td>HS-ESS2 &amp; MS-ESS2</td>
<td>Hands, representing plates, move apart for divergent boundary mid-oceanic ridge or rift valley (Fig. 1).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Move hands side to side for transform boundary. One hand sinks beneath another representing the subduction associated with a convergent boundary (Fig. 2).</td>
</tr>
</tbody>
</table>
RESULTS CONTINUED

TABLE 1. KALS ORGANIZED BY SUBJECT, CONCEPT, AND NGSS.

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<tr>
<th>KAL Concept</th>
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<tr>
<td><strong>Seasons</strong>&lt;sup&gt;MP&lt;/sup&gt;</td>
<td>MS-ESS1</td>
<td>Arrange in a circle around a central point representing the sun. Students bodily tilt toward Polaris and then rotate counterclockwise around the sun maintaining tilt to represent the seasons. Have students point to various locations on the celestial sphere to model the sun’s apparent movement across the sky by altitude and azimuth at various times of the day and year.</td>
</tr>
<tr>
<td><strong>Weathering Erosion &amp;Deposition</strong>&lt;sup&gt;U&lt;/sup&gt;</td>
<td>HS-ESS2 &amp; MS-ESS2</td>
<td>For weathering, have students make hand motions like they are crumbling a cookie, representing rocks breaking down in place (Fig. 3). Make wavy, flowy motion with arms to model erosive movement by wave, stream, or wind (Fig. 4); hands advancing together like an ice block for glaciers, and a fist tumbling down the arm for mass wasting. For deposition continuously stack hands, one on top of the other, to show how sediments pile up (Fig 5). Repeat these motions over and over, calling them out Simon Says-style, as a fun drill.</td>
</tr>
</tbody>
</table>

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Earth Science
<table>
<thead>
<tr>
<th>KAL Concept</th>
<th>NGSS</th>
<th>Activity Description.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Earth Science</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4Rock TypesLP</td>
<td>MS-ESS2</td>
<td>For sedimentary rocks put hands and arms on top of each other representing piling up of sediments. Igneous: make volcano with hands with fingertips touching, representing how some of these rocks are associated with volcanoes. Metamorphic: push palms together, really squeezing together (like making a snowball) representing formation by intense heat and pressure.</td>
</tr>
<tr>
<td>5Low Pressure Cell Cross SectionLP</td>
<td>MS-ESS2</td>
<td>Represent cross section circulation of low pressure cell by bringing hands outside your waist, then bring hands upward, almost meeting above your head, showing converging, rising air. Students then pulsate fingers to represent water vapor condensation on particulates and finally fingers falling from the cloud base representing precipitation.</td>
</tr>
<tr>
<td>5Low Pressure Cell in Map ViewLP</td>
<td>MS-ESS2</td>
<td>Display low pressure circulation (for the Northern Hemisphere) by moving your arm in a counterclockwise fashion or take your right hand and do a thumbs up sign. The upward pointing thumb shows rising air. Notice the way your fingers wrap around your palm: counterclockwise.</td>
</tr>
<tr>
<td>5High Pressure Cell Cross SectionLP</td>
<td>MS-ESS2</td>
<td>Represent cross section circulation of high pressure cell by bringing hands up above your head, then bring hands down and outward, showing diverging, subsiding air. Students “stamp out” rising, unstable air associated with clouds and precipitation by stomping their foot up and down.</td>
</tr>
<tr>
<td>KAL Concept</td>
<td>NGSS</td>
<td>Activity Description.</td>
</tr>
<tr>
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</tr>
<tr>
<td>High Pressure Cell in Map View</td>
<td>MS-ESS2-6</td>
<td>Demonstrate high pressure circulation in the map view (for the Northern Hemisphere) by moving your arm in a clockwise fashion or take your right hand and do a thumbs down sign. The downward pointing thumb shows sinking air. Notice the way your fingers wrap around your palm: clockwise.</td>
</tr>
<tr>
<td>Convection</td>
<td>MS-ESS2-6</td>
<td>Move right arm in clockwise fashion, left arm in counterclockwise fashion and you are modelling rising, sinking of convection currents.</td>
</tr>
<tr>
<td>Advection</td>
<td>MS-ESS2-6</td>
<td>Move either arm right or left, parallel to the surface to demonstrate advection.</td>
</tr>
<tr>
<td>Tornado Genesis</td>
<td>MS-ESS3-2</td>
<td>Roll pen between hands in horizontal position representing shearing causing an upper air vorticity. Then, continuing to roll pen, move hands to vertical position representing tilting due to strong updrafts. Tornado is formed when in the pen is rolling vertically.</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>MS-ESS2</td>
<td>To solidify this commonly confused weather concept, students mimic wind direction walking out of or from (not towards) a particular direction or azimuth.</td>
</tr>
<tr>
<td>River Erosion &amp; Deposition</td>
<td>HS-ESS2 &amp; MS-ESS2</td>
<td>In a large, open area, ask three to four students to hold hands. The inner most student is anchored and begins pulling the rest of the students around in a circle like playing a game of crack the whip. Outer most fast moving students are accelerating creating a cut bank, the slower, inner students, a point bar.</td>
</tr>
<tr>
<td>KAL Concept</td>
<td>NGSS</td>
<td>Activity Description.</td>
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<tr>
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</tr>
<tr>
<td>Oxygen-Carrying Capacity of Blood</td>
<td>HS-LS1</td>
<td>Students carry beads and tubes to demonstrate how blood carries oxygen, along with conditions that can affect oxygen in the blood.</td>
</tr>
<tr>
<td>Circulatory System</td>
<td>HS-LS1</td>
<td>Students move around the classroom in relation to blood and gas transport of the heart and lungs. Students act out speed and direction of blood in capillaries, veins, and arteries.</td>
</tr>
<tr>
<td>Mitosis &amp; Meiosis</td>
<td>HS-LS1</td>
<td>Students wear hats, name tags, or are assigned cards to guide their movement through the various stages of mitosis and meiosis.</td>
</tr>
<tr>
<td>The Neuron Game</td>
<td>HS-LS1</td>
<td>Students imitate neurons as they hold hands and squeeze to reenact action potential.</td>
</tr>
<tr>
<td>Mitosis</td>
<td>HS-LS1</td>
<td>Class, representing the cell membrane, circles around two pairs of students representing sister chromatids. Locked arms, two students with light jerseys are a single chromosome from one pair; another pair of students with locked arms wearing dark jerseys are a single chromosome from a second pair. Class makes two circles, representing two new cell membranes, students with jerseys double within original membrane before split occurs.</td>
</tr>
<tr>
<td>4 Mitosis</td>
<td>HS-LS1</td>
<td>Interphase: hands moving in a hand-washing motion showing the protein just “hanging out.” Prophase: waggle fingers together to show chromatin condensing to make chromosomes. Metaphase: line fingers loosely interlocked up in the middle. Anaphase: pull fingers apart and moving away, as chromosomes move to either side of cell. Telophase: make 2 fists as if you’re talking on the &quot;telo-phone&quot; to show the newly formed nuclei/cells, fingers representing chromosomes disappear from view in fists.</td>
</tr>
<tr>
<td>Muscle Movement</td>
<td>HS-LS1</td>
<td>Use students’ own appendages to act out simple terminology such as flexion and extension with arms and legs.</td>
</tr>
</tbody>
</table>
RESULTS CONTINUED

**TABLE 1. KALS ORGANIZED BY SUBJECT, CONCEPT, AND NGSS.**

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<tr>
<td>Atomic Orbitals&lt;sup&gt;LP&lt;/sup&gt;</td>
<td>HS-PS1</td>
<td>Students use move different parts of their body to display different atomic orbital shapes and then move those parts in different ways to represent various stretching vibrations during spectroscopy.</td>
</tr>
<tr>
<td>States of Matter&lt;sup&gt;LP&lt;/sup&gt;</td>
<td>MS-PS1</td>
<td>Solids: start with fists touching each other, ever so slowly moving them back and forth to represent the molecules in a solid being closely packed and slowly vibrating. Liquids: slide fists up and down opposite arms, moving faster than you were with solids to represent the molecules in a solid moving faster than in a solid, but able to slide and glide past each other. Gases: fists &quot;dancing&quot; in the air, moving faster yet, to represent the molecules in a solid moving very fast and far apart. This is also great for students when trying to describe whether or not molecular energy speeds up when going from one state to the other -- the hand motions help them to see, that when solids go straight to a gas (sublimation), the energy greatly increases as their hands go from being very close and tightly packed to fast and free moving.</td>
</tr>
<tr>
<td>Momentum, Balance, Kinematics&lt;sup&gt;MP&lt;/sup&gt;</td>
<td>HS-PS2</td>
<td>Students use their bodies to exert a force on force plates to display physics concepts on a computer program. Students jump from a platform elevated above the force plates onto the force plate to show their force of impact. Students are challenged to use the concepts they learned to lower that score.</td>
</tr>
<tr>
<td>Potential vs Kinetic Energy&lt;sup&gt;LP&lt;/sup&gt;</td>
<td>MS-PS3</td>
<td>Direct students to swing an arm in front them in a complete circle. At which point is potential and kinetic energy highest and lowest? At what point are these energies increasing and decreasing?</td>
</tr>
</tbody>
</table>
### TABLE 1. KALS ORGANIZED BY SUBJECT, CONCEPT, AND NGSS.

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<tbody>
<tr>
<td>7th Inertia</td>
<td>MS-PS2</td>
<td>Swing a partner around in an open space. Let go. What happens? Swing a partner around again. Try to stop suddenly. What happens?</td>
</tr>
<tr>
<td>7th Newton’s 2nd Law</td>
<td>MS-PS2</td>
<td>Students use the same bat and varying amounts of force to see the distance travelled by the ball. Repeat but use a heavier ball.</td>
</tr>
<tr>
<td>7th Newton’s 3rd Law</td>
<td>MS-PS2</td>
<td>Sit on a swing with a heavy ball or rock in your lap. Throw the ball forward. What happens to the swing?</td>
</tr>
<tr>
<td>7th Speed, Sound, &amp; Distance</td>
<td>HS-PS4</td>
<td>Students represent molecules and are lined up as different states of matter, close (solids), farther apart (liquid), farthest apart (gas). The transfer of sound is represented by the time it takes for students to tap the shoulders of the person in front of them.</td>
</tr>
<tr>
<td>5th Friction</td>
<td>K-PS2</td>
<td>Rub hands together to generate heat, representing friction.</td>
</tr>
<tr>
<td>5th Conduction</td>
<td>MS-PS3</td>
<td>Shake hands with classmate. Classmate’s hands colder? You are conducting heat away. Warmer? Classmate is conducting heat to you.</td>
</tr>
<tr>
<td>4th Conductors and Insulators</td>
<td>MS-PS3</td>
<td>For conductors, allow students to move between desks and chairs arranged neatly in rows, like that of metal atoms. They can complete this quickly. For insulators jumble up tables and chairs and have students navigate the same path as before. It will take longer representing how energy transfers are slower in this jumbled arrangement of “atoms”</td>
</tr>
</tbody>
</table>

*peer reviewed literature describing KALS **peer reviewed KALS with learning gains
without * or ** = anecdotal or web KALS
Numbered superscript = activity reference
(LP) = less planning, easy implementation (MP) = more planning required
RESULTS CONTINUED

TABLE 1. KALS ORGANIZED BY SUBJECT, CONCEPT, AND NGSS.

Our review indicates that only 3 of the 16 peer-reviewed articles reviewed (19%) had experimental data showing learning gains, with all of these articles featuring life science topics. Wyn and Stegink (2000), for example, reported that students acting as human chromosomes showed improvements in quiz scores compared to non-role playing classes. Gilbreth (2012), on the other hand, showed little or no gains in student learning but her activities involved simply “getting the blood moving” before a science lesson. This suggests that in order for KALs to be successful they must be activities designed specifically to model scientific concepts. No peer-reviewed articles showing learning gains were found for the earth and physical sciences.

When assigning KALs to NGSS we discovered activities to be split between the earth (46%), physical (34%) and life (20%) sciences. Most of the KALs target middle (49%) to high school-level (49%) standards. Only one activity, dealing with friction, could be considered an elementary NGSS. This finding, however, should be viewed with caution, as KALs can be adapted to a variety of age levels depending on instructor creativity and content knowledge.

Our sample was about evenly split between KALs classified as (LP) = less (50%) versus more (MP) (50%) planning. KALs designated as (LP) would be a good place to begin KALs implementation. “Tornado Genesis,” where students rotate a pencil from horizontal to vertical modelling tornado formation, would be one example. Another example would be using hand motions to mimic the diverging, transform, and converging plate tectonics boundaries. An example of a KALMP is the “Life Cycle of Stars” (Reinfeild and Hartman, 2008). In this activity, students act as particles in the envelope or core, using multiple movements to depict various stages of stellar evolution. This KAL, while conceptually more powerful, requires much more planning.

DISCUSSION

Students will find KALs fun, novel, and thought-provoking, but fully realizing KALs’ full potential depends on realizing their limitations, good class management, adequate assessment, and accommodating students with special needs.

First, KALs are simple models. Often they fail to capture the breadth, distribution, and temporal scales of complex natural phenomena. At best, KALs can only serve as a “close at hand” approximation. For example, stacking hands, one on top of one another to represent the burial and formation of sedimentary rocks, does not consider sedimentary rock formation by chemical precipitation.

Second, KALs will work best for teachers with good management skills. We recommend trying a KAL with volunteers before employing it in the classroom but once in class – take charge. Define terms while modelling KALs and while reciting instructions. Make it clear to students that while these activities are fun you see KALs as learning activities not playtime. It is critical that when a teacher is leading the activity, every student should be involved - NO EXCEPTIONS. When a teacher says, “everyone”, mean “everyone”. If KALs are done early and frequently in the year when establishing the classroom routine, there will be much more student buy-in.
Third, prompt higher-order thinking by asking students to evaluate the veracity/limitations of KALS models vis-à-vis the real world or how changing the way a KALS is performed (more force, different direction, change in timing) impacts the concept being modelled. Such questions align nicely with NGSS cross cutting concepts, especially systems and systems models and scale, proportion, and quantity. These crosscutting concepts can also be used to bridge science content with mathematics and social studies.

Finally, as we strive to make our classrooms more inclusive, KALS need to be accessible to students with special needs. Little, if any, research is available on how to adopt KALS for students with special needs. Furthermore, differentiating activities for students with special needs, cognitive, emotional, or physical, can be daunting. KALS, however, can be tailored to special needs students through simpler directions and unique guidance. For example, to demonstrate Newton’s third law principle, the class could be asked to stand and observe how pushing on the ground requires the reaction of the ground pushing back in order for jumping to take place. This can be done by a student in a wheelchair using his/her hand to push down on a desk. Another idea is pairing special needs students with a friend or teacher when movement is required around the classroom. Overall, the best suggestion for the inclusive KAL classroom is that teachers use their own creativity and compassion in adapting activities.

CONCLUSIONS

In this paper, we provide an introductory “one stop shop” review on a variety KALS, ranging from simply rubbing hands together to demonstrate friction to choreographing the life cycle of stars. While we see much potential in KALS, it should be pointed out that: 1) we did not provide pre-test/post-test data demonstrate learning gains. In this regard, there is a paucity of research documenting that KALS actually improve student learning. We encourage science educators to provide more experimental data corroborating the effectiveness of KALS. 2) Space only allows for overly terse descriptions of KALS in Table 1. Readers are encouraged to consult the original references for a complete description of procedures necessary to implement KALS.

We recognize that there are many more KALS out there, used by veteran teachers for years but these activities have yet to be widely disseminated. We hope to address this problem in the future through the creation of an online database archiving KALS for use by all science teachers. Send us your suggestions!

REFERENCES


Weis, N. 2015. Personal communication.

“To What Extent Should Students Learn Science Content Through Engaging in the Practice of Doing Science? Teacher Beliefs and NGSS Attitudes vs. Reported Classroom Practice”

Stephanie C. Tubman*, Brenda G. Bergman, and Jacqueline E. Huntoon, Michigan Technological University

BACKGROUND

Following adoption of the Michigan Science Standards (MSS) last November, Michigan educators are beginning a transition toward teaching science according to the vision of A Framework for K-12 Science Education (NRC, 2013). This transition is substantial, because the new standards call for a ‘three-dimensional’ approach to education in which students consistently engage in science and engineering practices (SEPs) as they learn disciplinary content and concepts that cut across science and engineering disciplines (NGSS Lead States, 2013).

The Framework and Next Generation Science Standards (NGSS) provide a sense of how science classes should change as a result of adopting the MSS, which are closely aligned to NGSS. Nevertheless, the way in which science classes will actually change will largely be influenced by teachers’ beliefs about, and attitudes toward, the standards (Davis, 2003; Czerniak, Lumpe, and Haney, 1999). Beliefs are often described as the personal convictions or ideas one holds, while groups of beliefs form attitudes or action agendas (Ajzen, 1985). Teachers’ beliefs have a powerful impact on whether and how they adopt new curriculum and teaching strategies (Cornett, Yoetis, and Terwilliger, 1990; Crawley and Salyer, 1995; Haney, Czerniak and Lumpe, 1996; Hashweh, 1996; McDevitt, Heikkinen, Alcorn, Ambrosio, and Gardner, 1993; Czerniak et al., 1999).

One issue that will influence how teachers adopt NGSS-aligned standards is teachers’ preexisting beliefs and attitudes about what constitute effective methods for science teaching and learning (Banilower, Trygstad, and Smith, 2015; Trygstad, Smith, Banilower, and Nelson, 2013). The Framework and NGSS describe a vision for science education in which students will primarily learn science concepts by engaging in SEPs. Students are to generate and interpret evidence and develop explanations through sustained investigations, all while increasing their capacity to direct all aspects of the process over time (National Research Council, 2012). This contrasts with the current state of science education in many classrooms, in which students primarily learn concepts through direct instruction with occasional reinforcement through engagement in SEPs (Banilower et al., 2015). According to results from the 2012 National Survey of Mathematics and Science Education (Banilower et al., 2013), around 60% of teachers believe that hands-on experimentation should reinforce concepts students have already learned, 40-50% of teachers believe that they should explain a concept to students before the students consider evidence related to the concept, and 90% of teachers believe that
vocabulary should come before conceptual understanding. Interventions to support teachers in adopting NGSS-aligned standards will need to take into account that many educators’ beliefs may not align with the notion of consistently teaching science content through SEPs, as envisioned by authors of the Framework and NGSS.

The objectives of the present work are to describe what a sample of Michigan science teachers thought about NGSS while the state of Michigan was on the verge of adopting the new Michigan Science Standards, explore the extent to which the teachers believed that SEPs were important for the learning of science content, and explore the extent to which teachers mentioned the use of SEPs when describing instructional methods used in a typical week in their classroom. Our purpose was to understand and document teacher attitudes toward an essential attribute of teaching and learning under NGSS in order to inform efforts to support educators during the transition to the MSS in Michigan.

STUDY CONTEXT

This study was conducted in conjunction with the Mi-STAR project (www.Mi-STAR.mtu.edu). Mi-STAR is working with several partner districts and universities around Michigan to develop and implement curriculum for the middle grades that is aligned with NGSS and the new MSS. Twenty-one teachers from schools across eleven Michigan school districts were interviewed from February through April of 2015. Teachers were identified as potential participants in one of two ways: (1) they were invited to interview during a visit of the Mi-STAR team to their district, or (2) they signed up to interview at the 2015 Michigan Science Teachers’ Association Annual Conference. None of the respondents had yet worked with Mi-STAR on curriculum development or curriculum implementation. Each respondent received a $10 gift card for their participation. Respondents had taught for an average of 16 years (range 9-23 years). Nine were from an urban district, eight from a suburban district, and four from a rural district. Eighteen of the teachers were female. At the time of interview, thirteen taught middle school science, five taught high school science, one taught high school science and math, one taught elementary science, and one was a teacher leader. In each interview, a respondent was asked 29 questions related to their instructional methods, beliefs about effective educational practices, and perspectives on reform-based education. Three questions were analyzed for this study (Table 1). Trained research assistants conducted all interviews. Interviews were transcribed and de-identified prior to analysis.

TABLE 1: SURVEY QUESTIONS INCLUDED IN ANALYSIS

<table>
<thead>
<tr>
<th>Question</th>
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<tbody>
<tr>
<td>“What kind of instructional methods do you use in a typical week in your classroom?”</td>
</tr>
<tr>
<td>“What do you think about the new science standards that are being considered for Michigan, which align with the new Next Generation Science Standards (NGSS)?”</td>
</tr>
<tr>
<td>“What educational practices best support student learning of science ideas (content)?”</td>
</tr>
</tbody>
</table>

Responses to the three questions were analyzed using latent content analysis (Downe Wamboldt, 1992). Themes or patterns within data were identified inductively, such that detailed readings of the raw data was used to derive themes (e.g., Frith and Gleeson, 2004; Braun and Clark, 2006). Coders identified underlying ideas that shape the semantic content of the respondents’ words (Braun and Clark, 2006). For example, if a respondent answered the question “What educational practices best support learning of science ideas?” by describing the importance of students engaging in activities such as asking questions, collecting data,
articulating their own explanations for observations, or defending their findings to other students, this was coded as engagement with the SEPs even if the respondent did not mention NGSS terminology.

One coder identified and defined an initial set of codes that summarize the data, and provided these to the second coder who analyzed the data against these categories (Mayring, 2014). The second coder used the definitions and codes, without presuming correctness of the descriptions or categories (Krippendorff, 2004). Any disagreements about codes and definitions were addressed through discussion (Lombard, Snyder-Duch, and Bracken, 2002). Each coder then independently refined coding of the full data set. The full data set was coded to minimize error associated with estimating disagreement based on only a subsample of the data (Krippendorff, 2004). Any disagreements were addressed through the method of discussion and resolution among the coders (Mayring, 2014; Lombard et al., 2002). For the question on NGSS attitudes, responses were coded both to identify respondents’ attitudes toward NGSS and to identify justifications respondents gave for their attitudes.

FINDINGS
In order to facilitate comparison between beliefs about effective science teaching and actual classroom practices, we present these together after findings on educators’ general attitudes toward NGSS.

EDUCATOR ATTITUDES TOWARDS NGSS
As shown in Table 2, more than half of the teacher respondents were supportive of the Michigan Science Standards (n=12), with most being supportive without qualification (n=7) and some being supportive with qualification (n=5). Of the non-supportive respondents, some were unfamiliar with the standards (n=5), while smaller numbers had a mixed opinion (n=2), or were concerned about their adoption (n=2).

<table>
<thead>
<tr>
<th>Theme</th>
<th>No. of respondents (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supportive</td>
<td>7</td>
</tr>
<tr>
<td>Supportive, with qualification or uncertainty</td>
<td>5</td>
</tr>
<tr>
<td>Unfamiliar</td>
<td>5</td>
</tr>
<tr>
<td>Mixed attitude</td>
<td>2</td>
</tr>
<tr>
<td>Concerned</td>
<td>2</td>
</tr>
</tbody>
</table>

Justifications for support. Among those teachers that indicated any degree of support, five respondents expressed the opinion that NGSS-aligned standards would work better in general than the current standards. Some respondents provided more specific reasoning for their support, including that the MSS would improve the way students learn science and that students would gain needed skills such as problem solving and the ability to think critically (Table 3). One respondent explained, “Why do we need to remember facts? That’s not our century. You can find out this stuff by doing a quick google search. Why are we having the kids remember it? We need to teach them, have more of a focus on problem solving.” Three teachers expressed that the new standards would benefit teachers because, for example, they would motivate teachers to...
improve and are better organized for teachers. Three respondents mentioned that they felt the standards would not require much change and that this was a positive thing.

Justifications for concern. Of the respondents who expressed any degree of concern, the most common concern was that NGSS would be challenging for teachers because it requires pedagogy that is unfamiliar, intimidating, or difficult (n=3, Table 3). One participant expressed strong concern that other teachers would be unable to implement the standards, saying, “[To teachers] it sounds like the same thing because it’s the same content but the problem is, nothing is really done to change teachers in 20 years of how they teach. I think the content is less important than how you teach. So the problem is, does the NGSS actually address how you teach? Yes, but it doesn’t show guiding light to teachers on how to do it.”

Other concerns related to issues teachers envisioned with implementation in their own classroom. Two respondents mentioned that they worried there would not be time to teach everything in depth. One respondent explained, “I’m just hoping we can do it in the time that we have within the school year and the school day. You know, be able to fit all of that into the time that we have with them. And cover that sufficiently. In a practical way that, where the kids get something out of it.” Another teacher was frustrated with the ambiguity surrounding state assessment of the potential Michigan Science Standards.

**TABLE 3: TEACHERS’ MOST FREQUENT REASONS FOR THEIR ATTITUDE TOWARD NGSS-ALIGNED STANDARDS**

<table>
<thead>
<tr>
<th>Reasons for support</th>
<th>N (of 12 total)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will work better than current standards (general)</td>
<td>5</td>
</tr>
<tr>
<td>Students will gain important skills</td>
<td>3</td>
</tr>
<tr>
<td>Will improve the way students learn science</td>
<td>3</td>
</tr>
<tr>
<td>Similar to old standards (not much of a change)</td>
<td>3</td>
</tr>
<tr>
<td>Allows for greater depth of teaching</td>
<td>2</td>
</tr>
<tr>
<td>Incorporates engineering</td>
<td>2</td>
</tr>
<tr>
<td>Necessary for students and society</td>
<td>1</td>
</tr>
<tr>
<td>Will motivate teachers to improve</td>
<td>1</td>
</tr>
<tr>
<td>Three-dimensional approach is good</td>
<td>1</td>
</tr>
<tr>
<td>More teacher-friendly organization</td>
<td>1</td>
</tr>
<tr>
<td>Michigan teachers had a lot of voice in the standards</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reasons for concern</th>
<th>N (of 9 total)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficult for teachers</td>
<td>3</td>
</tr>
<tr>
<td>May not have enough time to teach everything meaningfully</td>
<td>2</td>
</tr>
<tr>
<td>The transition will take work</td>
<td>1</td>
</tr>
<tr>
<td>State assessment is uncertain</td>
<td>1</td>
</tr>
<tr>
<td>Teachers will not be able to implement</td>
<td>1</td>
</tr>
<tr>
<td>The standards may easily be misinterpreted scientifically</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: ¹: From 12 respondents who expressed any degree of support. ²: From nine respondents who expressed any degree of concern.
BELIEFS ABOUT LEARNING SCIENCE CONTENT THROUGH PRACTICES

Teachers varied in their beliefs about the educational practices that are most supportive of student learning (Table 4). Their responses to the question “What educational practices best support student learning of science ideas (also known as content)?” were divided almost evenly between the following themes: students learn best through science practices, through experiences (no clear mention of science practices), through a mix of science practices and direct instruction, through a mixture of experiences (no clear mention of practices) and direct instruction, and when they are engaged (regardless of how they learn concepts).

TABLE 4. TEACHERS’ BELIEFS ABOUT WHICH EDUCATIONAL PRACTICES BEST SUPPORT STUDENT LEARNING OF SCIENCE CONCEPTS (N=21)

<table>
<thead>
<tr>
<th>Theme (number of respondents)</th>
<th>Example statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students best learn concepts by using science practices (i.e. questioning, investigation/experimentation, explanation, argumentation) (4)</td>
<td>“…They need to be able to experiment and touch and feel and question. Then once they’ve done that, to ask some questions that encourage them to continue their thinking or investigations.”</td>
</tr>
<tr>
<td>Students best learn concepts through a mix of science practices and direct instruction (e.g. teacher, textbook, video) (4)</td>
<td>“… That’s the big kick: get people moving with their hands. But you still have to tie it back to ideas and if we don’t have teachers that are trained in conceptual understanding, we’re never going to get concept across to kids. We’re going to do science and act them out but we’re still going to miss that connection to, why are we doing this in the first place? Doing science is great. There are times in which it’s ok to listen to a lecture and to absorb information, it’s just knowledge-based.”</td>
</tr>
<tr>
<td>Students best learn concepts through experiences (no clear mention of science practices) (5)</td>
<td>“Hands-on. Because they’re actually manipulating it and for me, that’s how I learned. I think back to when I was learning … I remember thinking, I have no idea what they’re talking about because I never saw it. I never got to do it. I really, I know myself as a learner and I need to put my hands on it. I need to see it.”</td>
</tr>
<tr>
<td>Students best learn concepts through a mix of experiential learning (no clear mention of practices) and direct instruction (e.g. teacher, textbook, video) (4)</td>
<td>“I think them being hands on learning instead of direct instruction, there will be a little bit of it just to give them some sort of direction and, you know, what they’re doing. But for them to experience things themselves, you know, hands on developing things... you’re always going to have some kids that prefer the reading, taking notes sort of portion. But I think the good majority of kids these days, they need to get in there with their hands and kind of experience all of that stuff.”</td>
</tr>
<tr>
<td>Students best learn concepts when they’re engaged, regardless of how they learn (4)</td>
<td>“You have to catch their interest. If they’re not interested they don’t care. I would think that would be the first, they have to be interested in the idea and they have to see how it relates to them.”</td>
</tr>
</tbody>
</table>
**INSTRUCTIONAL METHODS USED IN CLASSROOMS**

Teacher responses about their typical classroom instructional methods reveal that, at the time of response, students did not primarily learn through science practices in most respondents’ classrooms (Table 5). Only three teachers described the majority of instruction occurring through science practices in their classroom in a typical week, while four described students learning some content through practices. Two-thirds of respondents described their students as learning content through science practices rarely, or only through periodic labs.

**TABLE 5. TEACHERS’ BELIEFS ABOUT WHICH EDUCATIONAL PRACTICES BEST SUPPORT STUDENT LEARNING OF SCIENCE CONCEPTS (N=21)**

<table>
<thead>
<tr>
<th>Theme (number of respondents)</th>
<th>Example statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students usually learn science content through engaging in science practices (i.e. questioning, investigation/experimentation, explanation, argumentation) (3)</td>
<td>“My role in this, it’s more of a facilitator rather than a teacher. If kids ask me questions, I answer them with questions…. I’ll give you an example: they have to test the pH of some water samples… and they’ll come and say to me, what should it be? I’ll ask them what do you think it should be? I don’t give them an answer. They have to come up with it on their own. Then they have to explain why they came up with an answer and then based on their findings, is that water safe for drinking or not?”</td>
</tr>
<tr>
<td>Students learn some but not all content through practices (4)</td>
<td>“I do have some lecture, for content, to front-load them …. Sometimes they research it beforehand so they have a general knowledge beforehand so they have knowledge when I’m teaching the vocabulary, and other content. Then we do some type of hands-on project depending on the unit.”</td>
</tr>
<tr>
<td>Students usually do not learn content through practices, generally only during periodic labs (7)</td>
<td>“In a typical week I do anything from directing instruction, like giving notes, to answering questions on a worksheet. Generally I incorporate at least one lab activity every week in my classroom and we also spent some time every week doing some kind of silent sustained reading”</td>
</tr>
<tr>
<td>Students infrequently or never learn content through using practices experiences (7)</td>
<td>“I always talk. I probably do more teacher leading than is recommended.”</td>
</tr>
</tbody>
</table>

**BELIEFS ABOUT TEACHING COMPARED WITH INSTRUCTIONAL METHODS USED IN CLASSROOMS**

Some respondents’ beliefs about the educational methods that are most supportive of student learning were not always consistent with the actual instructional methods they used in the classroom. Of the four respondents who expressed that the best way for students to learn content was through science practices, one reported that their students infrequently or never learned through science practices. Of the four respondents who expressed that students best learned through a mixture of science practices and direct instruction, three infrequently or never taught using science practices.
DISCUSSION
These findings must be understood as a snapshot of a sample of Michigan teachers’ beliefs, attitudes, and practices prior to incorporation of the new MSS into their schools. This sample is not as a representation of Michigan science teachers as a whole. Limitations to the generalizability of the results include the fact that the sample is small and some participants in the study were self-selected. Recruitment methods were biased toward teachers with an interest in learning more about NGSS and a positive attitude toward standards reform and innovation.

Despite this study's limitations, the findings imply that there is not always a clear link between teacher attitudes about NGSS, beliefs about effective instruction, and teaching methods employed in the classroom. More than half of the teachers were supportive of NGSS. At the time of interview, however, one third of the teachers interviewed only occasionally had their students learn through SEPs, which took place during periodic labs. Another third infrequently or never had their students learn through science practices. Some teachers appear to engage students in science practices less frequently than they believe is ideal for student learning of science content. A disconnect between beliefs and practices could be the result of both internal and external constraints (e.g., Cross and Hong, 2009). While professional development programs are essential to supporting teachers in overcoming internal constraints, there is also a need to understand and address external constraints, such as teaching time or budgets, that may affect teachers’ classroom practices (Doyle and Ponder, 1977; Sparks 1983).

The results of this study support the value of a differentiated approach to supporting teachers during the transition to the newly adopted MSS. The needs of the smaller group of teachers who are supportive of the transition and often teach using SEPs will differ from those of teachers who are supportive but do not often teach through the SEPs. Likewise, the needs of those groups will differ from those who are intimidated by the standards or feel the transition is impractical or not worthwhile. Teachers who are supportive of the standards may be more likely to invest energy in the transition by actively educating themselves and seeking professional development opportunities and new curricula. Many of these teachers can be strong leaders and role models who are likely to have a positive influence on their peers (Jackson and Bruegmann, 2009).

Overall, the adoption of these new standards is more likely to be successful if as many teachers as possible perceive the transition as self-directed (Hargreaves 2007). Intimidated or skeptical teachers will need to have their voices heard. Approaches to engaging these teachers must recognize that in the context of reform, teachers’ emotional responses can influence their instructional practices (Cross and Hong, 2009). If the reform goal is not aligned with the teachers’ existing beliefs or identities, the call for reform can elicit negative emotions and ultimately rejection of reform-based practices (Cross and Hong, 2009). Skeptical teachers must therefore be engaged in experiences that are likely to increase the receptivity for the reform-based practices. Intensive and sustained professional development programs are more likely to yield positive outcomes. According to an analysis of 24 reform-based projects, professional development programs that are sustained for more than two weeks can have a positive influence on teacher practices, but programs sustained for four or more weeks are more likely to have positive influence on classroom culture (Supovitz and Turner, 2000).
CONCLUSION

Michigan teachers in this sample had varied attitudes toward NGSS. The majority of teachers who were familiar with the new standards were supportive of them, although several expressed qualifications of their support. A minority of teachers was strongly concerned about the new standards. Although most of the teachers interviewed supported NGSS, less than 20% of them believed that students best learn concepts primarily through SEPs, and only three of them instructed primarily through the SEPs in a typical week. Several teachers did not appear to teach content through SEPs to the extent that they believed was ideal for student learning. These results highlight that teacher beliefs about instruction are not always consistent with actual practices. Professional development initiatives will likely need to be differentiated and sustained in order to provide effective support to teachers. Sensitivity to teachers’ preexisting beliefs and attention to both internal and external constraints faced by teachers will be essential to the successful transition to the MSS.

ACKNOWLEDGEMENTS

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REFERENCES


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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; higher-
education 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 GRAD E**

**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.

ACKNOWLEDGEMENTS:
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SOURCES:


Appendix - Tables

**TABLE 1: MI-STAR THEMES***

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

<table>
<thead>
<tr>
<th>Built Environment</th>
<th>Earth and Space Systems</th>
<th>Energy and Earth Resources</th>
<th>Food and Agriculture</th>
<th>Public and Human Health</th>
<th>Sustainable Ecosystems</th>
<th>Water Resources</th>
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</table>

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

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.
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<th>TABLE 3: PROGRESSION OF DISCIPLINARY CORE IDEAS IN THE MI-STAR PROGRESSION MODEL</th>
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| **Unit 6.1:**  
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 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 8.1:**  
LS3.B: Variation of Traits  
LS4.B: Natural Selection  
LS4.C: Adaptation |
| **Unit 6.2:**  
PS1.B: Chemical Reactions  
| **Unit 7.2:**  
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 8.2:**  
LS4.A: Adaptation  
ESS1.C: The History of Planet Earth |
| **Unit 6.3:**  
LS1.A: Structure and Function |
| **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 8.3:**  
PS2.B: Types of Interactions  
PS4.A: Wave Properties  
PS4.B: Electromagnetic Radiation  
LS1.D: Information Processing |
| **Unit 6.4:**  
PS2.A: Wave Properties |
| **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 8.4:**  
LS3.B: Variation of Traits  
LS4.B: Natural Selection  
LS4.C: Adaptation |
| **Unit 6.5:**  
LS1.B: Growth and Development of Organisms  
LS2.A: Interdependent Relationships in Ecosystems  
ESS3.A: Natural Resources |
| **Unit 7.5:**  
LS1.B: Growth and Development of Organisms  
ESS3.C: Human Impacts and Earth Systems |
| **Unit 8.5:**  
ESS2.C: The Role of Water in Earth’s Surface Processes  
ESS2.D: Weather and Climate |
| **Unit 6.6:**  
LS2.A: Interdependent Relationships in Ecosystems  
LS2.C: Ecosystems Dynamics, Functioning, and Resilience  
ETS1.B: Developing Possible Solutions |
| **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 8.6:**  
PS4.C: Information Technologies and Instrumentation  
ESS1.C: The History of Planet Earth  
ESS3.B: Natural Hazards |
| **Unit 6.7:**  
PS3.D: Energy in Chemical Processes and Everyday Life  
LS2.B: Cycle of Matter and Energy Transfer in Ecosystems |
| **Unit 7.7:**  
ESS2.C: The Role of Water in Earth’s Surface Processes  
ESS3.A: Natural Resources |
| **Unit 8.7:**  
ESS2.D: Weather and Climate  
ESS3.C: Human Impacts and Earth Systems  
ESS3.D: Global Climate Change |
| **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 |
TABLE 4: PROGRESSION OF UNIFYING CROSSCUTTING CONCEPTS IN THE MI-STAR CURRICULUM

<table>
<thead>
<tr>
<th>Grade &amp; Semester</th>
<th>Unifying Crosscutting Concept</th>
<th>Unit-Based Crosscutting Concepts</th>
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<td>6th 1st</td>
<td>Systems and System Models</td>
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Let Us Tell You a Story…

Hedy: Actress, Film Star and Inventor

Have you used a cellphone or Wi-Fi network today? These modern technologies use spread-spectrum communications techniques that developed from methods invented during World War II for covertly guiding torpedoes. Behind the development of this technology is a fascinating story.

Hedy Lamarr was an Austrian actress who enjoyed a brief film career in Germany, including the first nude scene ever in cinema. This was controversial in the 1930’s and her husband, a military arms dealer in cahoots with Hitler, was not happy about it. He became extremely controlling and kept Hedy a virtual prisoner, preventing her from pursuing her acting career. When she did get to go out, it was only to attend lavish parties given by her husband while he conferred with scientists involved in military technology. Hedy was interested in science and curious about how it applied to the war effort. She nurtured this interest, talked to experts at parties and learned quite a bit from them. Then one night during a party, wearing all of her jewelry at once, she escaped and fled to Hollywood, where her agent promoted her as “the world’s most beautiful woman”.

Hedy was so attractive that one fan claimed that when her face appeared on film, everyone gasped because her beauty took everyone’s breath away. But Hedy said that to look glamorous “you just had to stand still and look stupid”. She was far from stupid, however. She read engineering books in her spare time and liked to tinker with designs. And she had good knowledge of military engineering from her ex-husband (some of it top secret). She discovered that her neighbor, George Antheil, a piano composer who explored mechanical sound in music, had compatible interests. Together they began to work.

The United States Navy was using radio-controlled torpedoes against its enemies in World War II. The radio signals carried information to steer the torpedo toward its target. But, if the enemy knew the frequency of the radio waves carrying this information, they could easily jam the signal or mess it up. Hedy and George had the idea of constantly changing the frequency of the radio signals being transmitted and received. As long as the transmitter on the ship and the receiver on the torpedo were coordinated to switch frequencies at exactly the same time, it should work! She and George designed a device that used the piano rolls from self-playing ‘player pianos’ also called pianolas. Continuous rolls of paper that ran through the
mechanism had perforations for each note. Patterns of perforations could play tunes on a player piano and, they realized, direct radio transmitters and receivers to change rapidly between 88 different frequencies - the same as the number of keys on a piano. When a piano roll ran in the transmitter and an identical one in the receiver, the two would be in synch. Anyone else tuning in to a particular frequency would only hear short blips. Hedy and George were awarded a patent for the design of this “frequency hopping” communications system.

To appreciate the security from interference that such a system provided, imagine that your favorite song came on the radio, but that it switched to a different and unknown channel every second. It would be impossible to listen to! This is how spread-spectrum technology hides a signal and kept torpedo guidance secret through frequency hopping. You can remember this the next time that you hear your favorite song on the radio or use your cell phone. And if you visit Hollywood, look for Hedy’s star on the Walk of Fame.

(Excerpt from Short Stories of Scientific History, Mystery and Discovery, Tinigin, McNeal and Schuster, 2016).

INCLUDING THE HISTORY OF SCIENCE IN SCIENCE TEACHING

Curiosity is innate in all of us. Children are always asking questions and wanting to know why. We all want to explore new things, expand our knowledge, understand the world, and make it a better place. And of course that is what science is all about.

As teachers, we are always seeking ways of nurturing students’ natural sense of wonder. One way to do that is to tell the story of how discoveries were made, enhanced with the personal stories of the scientists who contributed insights and ideas. This approach gives students a sense of what it is like to be part of scientific progress. If the history of science can be integrated into teaching, it can generate enthusiasm for science and celebrate the latent scientist in all of us. Michael Matthews (2014) argues that science education should include instruction both in science and about science. By interweaving science content, practices and history, we can also illustrate aspects of the nature of science.

Science is brimming with historical episodes that illustrate humanity’s quest to understand. If instruction connects students to this history, it can give context to the material, engage students, and illustrate what science is all about. To separate the ‘results’ of science from its history is to consider only a fragment of the whole scientific endeavor.

THE POWER OF STORIES

Besides being naturally curious, people love stories! Stories connect us, entertain us, teach us and inspire us. Stories based on the history of science are ideal to frame and enhance an inquiry-based approach to any topic and convey the human aspect of science. By telling stories of scientists’ lives and work, and infusing them into content instruction, teachers can help students see science as a creative intellectual endeavor. Yet, science is sometimes presented in school as a dry collection of facts and formulas to be learned, or as a set of instructions to be followed in lab activities. Too much of this can kill curiosity and enthusiasm, especially if tests consist of picking the right answer out of several wrong ones. But it need not be this way. Even if a textbook is a bit dreary, teachers can use interesting stories to liven
things up, spark interest and provide a connecting thread. Topics can be approached as stories of discovery and invention, with their challenges, setbacks and successes, including bits about the lives and times of the scientists themselves. Schank and Abelson (1995) argue that all meaningful human knowledge is based on stories!

Even rather ordinary science concepts like mass, volume, and density can come alive if we develop the ideas with questions and purpose, and tell intriguing stories along the way, such as the tale of Archimedes and the king’s crown. The king wanted to know whether the crown that had been made for him was pure gold or not, and Archimedes had been puzzling over how to find out without damaging the crown in any way. Legend has it that he immersed himself in the bathtub one day and noticed that the water level rose and he felt lighter. The answer suddenly came to him, and he jumped out and ran wet and naked down the street shouting in Greek “Eureka! (I have found it).” This story can motivate class discussion of the problem and the concepts involved. Students can suggest what he had ‘found’ and what he would have to do to solve the crown problem. The class could even try it in practice with some object (though maybe with some other material than gold!). Until the end the teacher might like to keep the class in suspense about whether the crown turned out to be pure gold and whether the makers were in trouble!

HISTORY OF SCIENCE AND NATURE OF SCIENCE IN THE NEXT GENERATION SCIENCE STANDARDS

The Next Generation Science Standards (NGSS) advocate the inclusion of case studies, stating: “The use of case studies from the history of science provides contexts in which to develop students’ understanding of the nature of science”.

Episodes from history are excellent ways of illustrating aspects of the nature of science through real examples. Appendix H of the standards gives examples of several areas of science where case studies would be useful, as follows.

- The Copernican Revolution
- Newtonian Mechanics
- Lyell’s Study of Patterns of Rocks and Fossils
- Progression from Continental Drift to Plate Tectonics
- Lavoisier/Dalton and Atomic Structure
- Darwin’s Theory of Biological Evolution and the Modern Synthesis
- Pasteur and the Germ Theory of Disease
- Rosalind Franklin, James Watson, Francis Crick, and DNA.

These are just a few examples, because, of course, all topics have interesting histories that show how science works. By using historical cases one can also promote basic understandings about the nature of science (NOS), such as the following that appear in the NOS Matrix of the NGSS, Appendix H:

- Science Addresses Questions About the Natural and Material World
- Science is a Human Endeavor
- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
• Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
• Scientific Knowledge Assumes an Order and Consistency in Natural Systems
• Science is a Way of Knowing

The NGSS advocate teaching both history of science and nature of science as a natural part of science instruction.

OUR PROJECT - A BOOKLET OF HISTORICAL VIGNETTES

Even if teachers are enthusiastic about including history in their science teaching, they would still have to find, read, and select material from the history of science, and write it into their lessons. Finding the time to do this for a range of topics is daunting, given everything else that teachers have to do. So, we launched a project, “Exciting Students through History” to create an easy-to-use resource that would help teachers infuse history into science instruction. Our vision was to create a booklet containing short stories or ‘vignettes’ about scientists and their contributions, in a form could be used to enliven lessons and add historical context. Infused into science lessons, such accounts could take just a little time during content instruction, but if well done, could pay off in first arousing students’ interest and then broadening their appreciation of science.

While we anticipated that the booklet would serve mainly as a teacher resource, students could read it too. The vignettes are accessible at multiple grade levels and include scientists from each of the domains in the Disciplinary Core Ideas in the NGSS. With support from a Michigan State Teachers’ Association mini-grant, we wrote and printed a booklet, Short Stories of Scientific History, Mystery and Discovery. At present, the booklet contains stories of nineteen scientists, accompanied by pictures and references for further reading. We also wanted to highlight the accomplishments of women scientists. We first shared the project in workshops at the MSTA and NSTA 2016 annual meetings where we distributed the booklets and welcomed comment. From continuing feedback, we hope to expand the project to an interactive website to host vignettes and provide a forum for sharing ideas.

PUTTING THE PROJECT INTO PRACTICE – A CLASSROOM EXAMPLE

We illustrate how the booklet might be used by giving an example of teaching the periodic table of the elements. This important science topic is relevant to the atomic nature of matter, the elements found in nature, and their properties. Michigan K-12 Standards for Science standards include the following statements relating to the periodic table.

• HS-PS. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
• HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

Dimitri Mendeleev, a Russian scientist, had the crucial insight that led to his development of the periodic table, building on the work of many who had gone before, and making sense of it all. Below is the vignette from our booklet about Dimitri and how he accomplished this.
Dmitri and his Table of the Elements

Dmitri Mendeleev, born in 1834, grew up in Siberia, a part of Russia with small villages and bitter cold. He was the youngest of many siblings. (There were so many that nobody really knows how many there were.) Fortunately for Dmitri, he managed to garner favoritism from his mother. (Isn’t this always the case with the youngest?) This especially comes in handy when your life is somewhat miserable. And their life wasn’t all that great with so many mouths to feed, freezing cold, Dmitri’s dad went blind and his mother was trying to keep the family’s glass factory going just to keep food on the table. Can you even imagine?

Dmitri’s father died when he was thirteen, then the glass factory burned. (Can this story get any worse?) At wits end and determined that her youngest (and favorite) child was not to be left eking out a meager life in the Siberian hinterland, Mrs. Mendeleev packed up young Dmitri and traveled by horseback 1,200 miles over the Ural Mountains to Moscow. How amazing is that? Once there, she delivered him to the doorstep of an elite university, and they promptly denied him admission. Undeterred, she said, “Dmitri, get back on your horse” and they continued another 400 miles to St. Petersburg where he secured admission to his father’s alma mater. Then sadly, his mother died, but she died happy in the knowledge that Dmitri was launched in his academic career.

Mendeleev successfully completed his degree, became a charismatic professor and a noted chemist. At the time, many chemical elements had been isolated and described. There was, however, no formal system of organization. This intrigued Mendeleev and he sought patterns that would help him organize the elements into a table. He made flash cards of the elements and recorded on each card the name of an element and everything known about the element. Since he was a frequent train traveler, he would pass time on the train by “playing” with his element flash cards. After many, many, many train rides, Mendeleev came up with a solution…..a table that organized the elements by increasing atomic mass and produced a repeating pattern of physical and chemical properties. Using this pattern, the elements naturally fell into groups with similar properties, in the same way that days of the week are in vertical columns on a calendar, although quite a bit more complicated. But, here was Mendeleev’s real genius: he realized that there were gaps. He knew that he was missing some “yet to be discovered” elements. The patterns in his table gave him hints about those elements. So, Mendeleev made some very bold predictions. He said to everyone out there in the chemistry world, “I predict that a new element will be discovered. It will be a metal and it will be soft and silvery. And I predict that its atomic mass will be around 70 atomic mass units.” He figured this out by looking at the properties of aluminum above the gap in the table and the atomic mass of zinc next to it. The subsequent discovery of the element gallium in 1875 amazed people. Also remarkable is the fact that gallium has such a low melting point that it will melt in your hand. So, don’t try making jewelry with it.

(Excerpt from Short Stories of Scientific History, Mystery and Discovery, Tinigin, McNeal and Schuster, 2016).
How could this story about Dimitri spark the design of an innovative classroom lesson on the periodic table? What follows is a suggested middle school lesson that draws on the vignette to enliven learning. Dimitri’s story is told as an introduction to a class activity analogous to Dimitri’s original card-sorting on the train. The teacher prepares by gathering sets of objects fitting into four categories, such as blocks, balls, washers and strips, that have different masses and can be ordered sequentially. These objects are organized into paper bags, each containing 17 objects that fit into the categories. Student groups each receive a bag and a set of notecards. For each object, they measure its mass, and record the object’s name, mass and a physical description on a notecard. They repeat this for all 17 items to get 17 cards with information. Then, they sort the completed notecards in order of increasing mass. Next, they lay the cards out in rows, in order of mass, while looking for a repeating pattern to prompt them to start another row and thus organize the objects into groups. The teacher has prepared everything in advance so that there are three objects “missing”, and the challenge for students is to recognize this and identify where the gaps in the layout lie. For each of the missing objects, students can predict what kind of object it should be, as well as its mass and physical properties, based on its location in the whole ‘table’ and the attributes of its group.

The entire activity takes about three class periods. The objective is to have the students see patterns in their layout of cards, and use the explanatory and predictive power that this provides. Through this analogy activity they will be participating in some of the practices of science! At the same time they will gain a better understanding of the nature and purpose of the periodic table, recognize the challenges Dimitri Mendeleeev faced in its historical development, and appreciate his intellectual accomplishment.

THE PROJECT CONTINUES

We are encouraged by the positive response from our workshop participants. The enthusiasm over the stories produced so far reflects an interest in history and an affinity for storytelling. Everybody loves a good story! The feedback endorses the idea that stories are an effective pedagogy and a way of integrating history and the nature of science into content instruction. The vignettes in our booklet are deliberately short and sweet, but we hope teachers will feel encouraged to expand on them to fit their own needs and design their lessons accordingly.

Knowledge of the historical dimension of science promotes a richer view of both science and of science education (Matthews, 2014). Our students can get a sense of being participants in the human quest for understanding the natural world by learning the fascinating history of this quest.

Finally, going back to Hedy’s vignette at the beginning, note that the NGSS and the new Michigan K-12 Standards for Science include waves, radio communications, signals and information, so Hedy’s story could fit right in!

ACKNOWLEDGEMENT

A mini-grant from the MSTA enabled us to print booklets for distribution to workshop participants at the 2016 MSTA and NSTA conferences.
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REFERENCES


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Building Micro Underwater Gliders: Lesson Plan for Exploring Engineering Design and Understanding Forces and Interaction

Saeedeh Ziaee Fard, Graduate Research Assistant and Nina Mahmoudian, Assistant Professor, Michigan Technological University

ABSTRACT

This paper aims to provide a classroom activity to explore engineering design inspired by underwater robots that are used for ocean exploration. The activity can be easily adopted in middle school classrooms by teachers with no background in engineering and robotics who seek innovative ways to connect disciplinary core ideas and standards to the concepts they need to teach. These types of activities stimulate analytical thinking and integrative design skills in students and encourage social interactions with team partners.

BACKGROUND

Underwater robotics is an emerging science and is evolving rapidly. 71% of earth’s surface is covered with water and oceans occupy 96.5% of this water [5]. To explore this enormous and largely unknown area, scientist developed various autonomous underwater vehicles (AUVs). Underwater gliders (UGs) are a special form of AUVs that propel themselves in a saw-tooth like pattern through water by changing buoyancy. The forward motion is induced by hydrodynamic forces on the wing. UGs traverse in water with lower speed. Scientists use this drawback to their advantage and collect sensory data while the UGs travel underwater on long mission with a single battery life. Figure 1 depicts the glider saw-tooth pattern.

FIGURE 1: UNDERWATER GLIDER (UG) SAW-TOOTH PATTERN
UGs play an important role in solving some of today’s most pressing environmental, safety, and biological challenges. Commercial UGs have been used for long-term, basin-scale oceanographic sampling for the purpose of predicting climate change patterns and measuring dangerous containments such as oil spills. Increasingly, the military depends on them for littoral surveillance and other applications.

At the Nonlinear and Autonomous Systems Laboratory (NASLab) in Michigan Technological University, we developed an affordable and innovative glider for underwater problem-solving and promotion of interest in engineering (GUPPIE) for middle school and high school students [3], [7].

GUPPIE was developed to be a “fun” hands-on learning platform that allows students to design a vehicle capable of collecting underwater data. Students as early as 4th grade learn how UGs work, gather data and help with the environmental crisis through underwater structure inspection or invasive species observation.

During their experience with GUPPIE, they learn and practice engineering process throughout the course. Every individual uses the engineering process in daily life without noticing it. We highlight the main factors in the process and repeat them until mastered [7].

**FIGURE 2: MIDDLE SCHOOL STUDENTS SWIMMING WITH GUPPIE**

![Middle school students swimming with GUPPIE](image)

Water quality is important to us and I like the idea of having hundreds of sensors out in the water always taking water samples. ~2013 Water Festival Participant

**STEPS OF THE ENGINEERING PROCESS**

Figure 3 illustrates the six stages of developing engineering solutions including ask, imagine, plan/brainstorm, create/build, test/validation, and improve/redesign. First
step in the engineering process is to identify the problem and ask the right question. In the GUPPIE project for example, students need to design and build a mechanism that can glide forward down in the water and glide back up to the surface autonomously. Following this step, comes the creativity and problem-solving phase. To imagine the possible solution, one explores different aspects of the problem by utilizing different resources from informative websites to journal papers and textbooks. The next step is to brainstorm and analyze different criterion associated with the problem and the solution; plan the project in terms of cost, time and outcome. By completing the framework, prototyping and production based on the execution the plan begins. The product goes through testing and the performance and requirements get validated. If the requirements are not met, design improvement is necessary and step 1-5 have to be repeated.  Students practice these stages repeatedly in GUPPIE project within our various robotics program and water festival. With GUPPIE, students realize how the engineering process comes together and how robots can help people to explore the environment [6]. This helps them make explicit connections between engineering core concepts and the skills needed to solve some of today’s most pressing problems. To date, a total of 542 4th-12th grade students have attended GUPPIE sessions in 2012-2015 [1]. More information about NASLab activities are available in http://me.sites.mtu.edu/mahmoudian/outreach/ and http://me.sites.mtu.edu/mahmoudian/research/co-robot_nri_guppie/.

FIGURE 3: ENGINEERING PROCESS FLOWCHART

MICRO UNDERWATER GLIDER (MICROUG)

In our sessions, to demonstrate the concept of UGs we introduce an innovative and low-cost experiment using craft sticks and paper clips called Building a Micro Underwater Glider (microUG). The fundamental forces behind UG motion are buoyancy and gravity. We use paper clips to simulate the weight of the UG and to manipulate the effect of the gravity. Craft sticks help to alter the buoyancy and lift force. Since craft sticks are buoyant objects; by adding weight (paper clips) we can adjust the buoyancy of the craft sticks in the water to make them sink (negatively buoyant) and rise (positively buoyant). The basic microUG is simply made by two craft sticks
and three or more paper clips. However, the design can be revamped to achieve better results. The advantage of this experiment is that the design outcomes are unique to each group but equally creative and functional. The activity is exciting and engages students of different age groups. Figure 4 depicts the setup of this experiment. The list of the required items are as follows:

- craft stick (preferably with no color to avoid hazy water after couple of runs)
- paper clips
- small aquarium or water tank with minimum dimension of 10”x20”
- paper towel
- sharpie
- ruler
- paper and pen to register the score

FIGURE 4: MICROUG EXPERIMENT SETUP

LESSON PLAN: DESIGNING, BUILDING, AND TESTING OF A MICROUG

At the beginning of the session, students are given a context for learning by first understanding the applications of a UG. The importance of water is explained using local pictures and stories students can relate to. These photos shape a broader context for the importance of Great Lakes research related to monitoring fish populations, algae blooms, invasive species, and contaminants. After the context for learning is set, the teacher/instructor explains how UG works by illustrating a real life glider trajectory at [2].

This provides great anticipation, and then students have the opportunity to design, build and test their own microUGs. The teacher demonstrates how to build a microUG using two craft sticks and a few paper clips. This is to test the microUG in the aquarium to show how microUG dives into the bottom of the tank. The teacher explains that the microUG in this experiment can only dive downwards since it doesn’t have the
mechanism to change the buoyancy autonomously while underwater. It is possible to glide back to the surface by manually removing the paper clips. The teacher can demonstrate this.

After the demonstration, students can start the engineering process of building microUG by collaboration and interaction with their team partners. They follow the engineering flowchart to build their prototype and test it. Figure 5 depicts the microUG test in the aquarium by the middle school students.

**FIGURE 5: MICROUG IN WATER**

MicroUG can be tested through various validation missions, exploring concepts and testing distance, speed, buoyancy pathways and limiting resources:

1. Glide the microUG as far as possible: students have 3 runs and the most distance traveled counts towards the score. The distance is the length between the front walls of the aquarium, where the glider started its motion, up to the tail of the glider at the bottom of the tank. It can be marked on the longer wall of the aquarium with a sharpie as shown in figure 6. The longest distance will be measured and MicroUG earns 3 points per inch traveled. The scoring setup is flexible and can be altered. Figure 7 shows a fourth grader engaged in creating a microUG in a water festival hosted by NASLab [6].

2. Race two microUGs; the fastest is the winner.

3. Hold microUG buoyant underwater: the distance can be recorded either from the water surface or the bottom of the tank. To neutrally balance the microUG, students need to find the zero buoyant point for their prototype. MicroUG will
stay motionless (static) at this state and the measurement can be recorded.

4. Spiral down microUG (requires a taller aquarium); students need to add counterbalance weight (paper clip) to their MicroUG to generate the turn motion on the wing. If the aquarium is deep enough, the MicroUG will follow a spiral path down to the bottom on the tank.

FIGURE 6: INSTRUCTOR MARKS THE DISTANCE

5. Use minimum number of craft sticks and paper clips.

6. Rise of microUG to surface (minimum removed paper clips wins); students can remove one or two paper clips manually when their microUG is seated on the tank floor. Without any upward force from student the glider should travel back to the surface. A microUG can swim upward in vertical, nose first or tail first manner. To make this task more challenging, the microUG that glides nose up receives bonus point.

The time limitation of each mission can vary depending on the age group and the number of participants. After completing the microUG, each team/individual has three opportunities to test their microUG to evaluate their prototype.

Upon completing this inexpensive and creative experiment, students understand force interactions with robot motion underwater, and how a UG thrusts in water without requiring a motorized propeller by manipulating gravity and buoyancy forces. This type of hands-on activity stimulates a sense of satisfaction and increase student’s motivation towards science, engineering and robotics. Observing different microUG designs as illustrated in Figure 8 built by different age groups proves that this experiment can successfully spark creativity and ingenuity in the students.

MICROUG AND NGSS CORRELATION: AN INNOVATIVE PATHWAY TO CORE IDEAS

The microUG in-class activities are in conjunction with the Next Generation Science Standards (NGSS) disciplinary core ideas. MicroUG activities introduce students to engineering design, motion and stability, forces and interactions.

The core idea of engineering (MS-ET S1-1 to MS-ET S1-4) consists of three concepts: defining the engineering problem, proposing the solution to the problem, and
The microUG challenge covers all three components by asking the question of how an UG propagates through water, how to build a microUG, and how to improve a microUG to go faster or perform certain mission respectively. The microUG lesson plan also supports the NGSS performance expectations.

The science behind the microUG can be explained in terms of motion and stability, forces and interaction (MS-P S2-2 and MS-PS2-5). A microUG interacts with water in the aquarium. The changes in the direction of microUG are determined with respect to the aquarium reference frame. All forces are evaluated with respect to microUG body frame (MS-PS2-2). During this experiment, teachers can explain the difference between the reference frames.

Motion of the microUG depends on interaction of three forces applied: gravity, buoyancy, and lift. The gravitational force is an attractive force between the earth and the microUG (PS2.B). The buoyancy force is the reaction of the environment (water) acting on the microUG and opposes the gravity, hence inducing upward force on the microUG. The sum of gravity and buoyancy forces determines whether a microUG travels upward or downward. The lift force on the wing translates the vertical motion to forward motion. If sum of gravity and buoyancy forces is zero then the microUG is neutrally buoyant and has no motion. MicroUG in-class activities can help the students to visualize these forces.

In conclusion, teachers can employ this innovative in-class activity to explain the key definitions in forces and interaction, and provide their students an opportunity to explore engineering design concepts.
ACKNOWLEDGEMENTS
This work is supported by National Science Foundation under grant NSF-1426989.

LITERATURE CITED
Co-Robots to Engage Next Generation of Students in STEM Learning, http://me.sites.mtu.edu/mahmoudian/research/co-robot_nri_guppie/

Low-Cost Underwater Glider ROUGHIE, https://www.youtube.com/watch?v=hmR4o2ueaK0&index=6&list=PLkMYgm8PFAwYqb8ZoOA1JWI159sfrDKTG


Outreach, Nonlinear and Autonomous Systems Lab., http://me.sites.mtu.edu/mahmoudian/outreach/

Practicing Citizen Science: An Investigation of Schoolyard Resource Availability and Population Dynamics

Ms. Erin Koren, Pre-service teacher, Grand Valley State University, Ms. Jamie Meaney, Pre-service teacher, Grand Valley State University, Associate Professor Gary Roloff, Department of Fisheries and Wildlife, Michigan State University, Professor Christopher Dobson, Department of Biology, Grand Valley State University and Associate Professor Joseph Jacquot, Department of Biology, Grand Valley State University

INTRODUCTION AND RATIONALE FOR ACTIVITY

As pre-service science education majors at Grand Valley State University, we are deeply entrenched in learning the theories and methods of teaching science through inquiry. We have created a lesson that middle school teachers could use to put this theory into practice, while still making sure to hit appropriate Next Generation Science Standards (NGSS Lead States 2013). This lesson could address the following NGSS performance expectations for middle school life science related to matter and energy in organisms and ecosystems:

• **MS-LS2-1.** Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
• **MS-LS2-3.** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
• **MS-LS2-4.** Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

In addressing these performance expectations, this lesson focuses on the following science and engineering practices, disciplinary core ideas, and crosscutting concepts:

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in Argument from Evidence</td>
<td>LS2.B: Cycle of Matter and Energy Transfer in Ecosystems</td>
<td>Energy and Matter</td>
</tr>
<tr>
<td></td>
<td>LS2.C: Ecosystem Dynamics, Functioning, and Resilience</td>
<td>Stability and Change</td>
</tr>
</tbody>
</table>

For a thorough description of related Common Core State Standards in English Language Arts/Literacy and Mathematics (NGAC and CCSS 2010) view the standards on the NGSSS website (http://www.nextgenscience.org/dci-arrangement/ms-ls2-ecosystems-interactions-energy-and-dynamics).
This activity will take students through a 5E learning cycle, centered on the question of how resource availability affects wildlife populations. For references about the 5E learning cycle and inquiry learning, we recommend Llewellyn (2004) and Llewellyn (2011) and information from Biology Sciences Curriculum Study (BSCS 2016). This lesson will guide students to understand the interconnection of organisms within their local ecosystems. The learning sequence we will provide starts with students making observations of plant and animal interactions in their ecosystem. Your students will draw conclusions from graphic data about how food availability directly drives animal populations.

This field-based activity directly addresses the concerns expressed by the No Child Left Inside movement (Benbow & Camphire, 2008). Students will investigate the natural world outside their classroom and explore their local environment. One of the most authentic ways to study ecology and species interaction is to go outdoors and observe it firsthand. By getting your class outdoors, we hope you can spread an appreciation for the natural world among your students.

THE PURPOSE OF THE MI-MAST WILDLIFE FOOD TRACKER AND APPLICABILITY TO CLASSROOMS

Gary Roloff, a professor in the Department of Fisheries and Wildlife at Michigan State University, heads the MI-MAST program, in partnership with the Michigan Department of Natural Resources and Michigan United Conservation Clubs. This research team is working to conserve wildlife in Michigan, and, to do this, they need the help of citizen scientists across Michigan. Conservation management plans depend greatly on ensuring wildlife have access to the food sources they need to survive and reproduce. Some of the important food sources for Michigan’s wildlife fauna are mast crops. Mast crops are species that produce a large number of seeds or fruit synchronously at some interval—usually every two or more years. The MI-MAST program is looking for long term data on the production cycles of mast producing trees and shrubs around the state and this effort could greatly benefit from the help of teachers, like YOU, who have access to the same mast-producing species annually on or near your school grounds. However, conservation efforts are not all that benefit from this program. The longer you have students collecting data, the more meaningful data your students will have to work with. As a long-term classroom project, you may decide to compare mast production year to year or investigate which species bear the most mast.
Wildlife biologists are asking for assistance in collecting mast data throughout Michigan using the MI-MAST app. We are inviting you to participate in citizen science, and by extension, have your students do so as well. With citizen science, the public, including our students, can participate in data collection that is authentic and that will contribute to building knowledge in the scientific community (Metz, 2015). In order to obtain data to construct conservation plans for Michigan wildlife, the MI-MAST program needs information about the cycles of mast production in trees and shrubs all across the state; active classroom participation will allow this research to take place across scales no single research team could reasonably reach. Perhaps most importantly, the contribution of citizen science towards student engagement is enormous. By engaging in citizen science, students can experience more than contrived, ‘cookbook’ labs where the outcome is fixed. Instead, they can discover the inquiry-based, complex nature of science (Metz, 2015). While this lesson presents a great way to get students outdoors to collect authentic data, as teachers we must be prepared to be flexible and allow ourselves to be comfortable with not having all of the ‘right answers’ ahead of time.
You can access the MI-MAST program through a mobile device or through a desktop computer (http://www.mimast.org/). To log observations in the field, students will need to have their own device and use cellular data. With a mobile device, you can take pictures, make observations of mast availability, and record a direct GPS location right in the field. However, if this mode of data submission is not right for your classroom, you also have the option of recording observations outside and uploading information back in the classroom on desktop computers. You will find printable fact sheets with pictures and descriptions of each mast-producing species to assist with tree and shrub identification on MI-MAST in the “Fact Sheet Printouts” tab under “Tools” (see Figure 2).

**LOGISTICAL CONSIDERATIONS:**

- Most likely, only trees and shrubs producing hard mast (i.e., acorns, hickory nuts, beechnuts, and walnuts) will be available to collect data in the fall during school, you will typically collect data on soft mast, like cherries, raspberries and blackberries, during summer months.

- Before taking your class outdoors, it will be important to scope out an area on your school grounds or in a local green space where you can find mast-producing species. Whenever conducting class outside, student safety is paramount. We suggest checking the area ahead of time for potential hazards such as poison ivy/poison oak and nearby streets with heavy traffic. Depending on the dynamics of the class, it could be important to set boundaries for students about how far they can explore.

- When planning this activity, we envisioned students working in small groups to gather and analyze data. Since this activity promotes the value of citizen science, we wanted students to gain real life experiences, in line with the nature of science, which
almost always involves collaborative exploration and analysis.

- Be sure to observe best practices for safe outdoor learning. Students should wear pants and closed-toed shoes, avoid eating the mast, and wash their hands after exploring outdoors. If poison ivy or oak are present in your study area, show students how to identify it and specific areas to avoid.

- You will need to add the location of each tree or shrub observed in your class. The MI-MAST program will ask for the latitude and longitude of each individual tree or shrub. If your students are using a mobile device, the program automatically records the coordinates. If you upload data back in the classroom on a non-mobile device, the coordinates can be determined with a GPS device, a cell phone using a free compass application, or google maps (https://www.google.com/maps).

- After you add the location of the tree or shrub, you will then enter a new observation to indicate the amount of mast present.

- The MI-MAST program stores your data, which you can access at any time. The
program also produces an annual report that lets you see how your mast observations compare to other observations from around the state.

5E Learning Cycle Format - *(Day 1)*

1. **ENGAGE:**

On the first day of this lesson, students will break into groups and use a “Chalk Talk” to assess their prior knowledge on the topics of plant and animal interactions within an ecosystem (see Table 2). We would recommend groups devote about two minutes for each question, but you can adjust this time to fit any class period length. As groups move around the room answering questions, have them tally or highlight statements they agree with that other groups have made. With a chalk talk each student is given the opportunity to find their ‘voice’ in the classroom and students are prompted to react and make connections with others’ responses (Ritchhart et al., 2011, p. 78). We recommend wrapping up this phase with a class discussion where you analyze all responses for common trends in thought and misconceptions.

| TABLE 2. EXAMPLES OF QUESTIONS TO DRAW OUT STUDENTS’ PRIOR KNOWLEDGE OF PLANTS AND ANIMALS DURING INITIAL ENGAGEMENT. |
|*The list of Michigan animals in Figure 3 matches the wildlife targeted by the MI-MAST program. The MI-MAST app includes fact sheets with dietary preferences for each species.* |

| **Sample “Chalk Talk” Questions** |
| What are your favorite animals in Michigan? |
| What trees would you find locally? |
| What local trees and shrubs produce nuts, acorns, or berries? |
| What sort of wildlife do you think our school grounds could support? |
| Provide students with a list of Michigan animals (e.g., black bear, turkey, grey squirrel, coyote, red fox, white-tailed deer) and ask them what they think the preferred diet of each animal.* |

...
Your questions should be designed to get students focused on the material in the lesson. Additionally, this engage activity will get students thinking about how population ecology affects their local Michigan environment, including school grounds or local green space.

During this step of the learning cycle, inform students about the purpose of MI-MAST that of conservation of Michigan wildlife and that their data collection will contribute towards this goal. Emphasizing this point will raise the level of authenticity and motivate students to do their best work. We suggest navigating to the MI-MAST website with your class and reading through the “About” section that describes the purpose of the program. We recommend ending this phase by asking students:

- How do you predict mast affects animal populations? How would you be able to determine this?
2. EXPLORE:
First, students will go outside and explore within the boundaries defined by their teacher. Refer to the “Submitting Data to MI-MAST: Wildlife Food Tracker” section of the paper for instructions on how to upload data. Remember that you will have to decide whether students will upload data from their mobile devices or back in the classroom on non-mobile devices. If students will be uploading data back in the classroom, instruct students to create a data table to represent the following observations: tree or shrub species, mast type (hard or soft), date, amount of mast, description, possible evidence of wildlife. Note that for the quantifying the amount of mast, MI-MAST asks citizen scientists to choose between three categories: none, few, or many. For hard mast, ‘few’ means less than one-third of the tree has nuts, and ‘many’ requires that more than one-third of the tree has nuts. For soft mast, ‘few’ means few fruits are present that may be small or shriveled, and ‘many’ means fruits are abundant and in good condition. Recording the trees and shrubs outlined in the fact sheets that do not have mast in any given season is also valuable for the work of researchers developing wildlife management plans.

(Day 2)

3. EXPLAIN:
You collected data, and on the second day, it’s time to have your students examine and explain what your data means. In this activity, have your students work in groups to interpret the data collected to predict what wildlife could be supported on the school grounds or local green space. Students can reference the printable fact sheets of the mast species from the MI-MAST website, which lists the types of mast each wildlife species consumes. You will find these printable fact sheets under the “Tools” tab on the MI-MAST website. As a class, have your students compile your list of species to identify all possible supported wildlife.

Afterwards, ask students to verify which wildlife could be present at their study site with interactive range maps from the Map of Life from Yale University (https://mol.org/species/). On this website, there is a base map and three drop down tabs in the upper right corner. Figure 4 below provides an example of the map view. In the first “Select a region” tab, type in Michigan. In the next tab, you will select particular taxa, such as “mammals” or “birds.” Lastly, you will enter the common name of the species as listed in MI-MAST. Note that for Bobwhite Quail the common name on the Map of Life is Northern Bobwhite and the Pheasant is the Common Pheasant. Range maps are available for ten of the 11 wildlife species targeted in MI-MAST, the exception is the elk. The only mammal you will not find data for is the elk, which were reintroduced to a small area in Michigan. More information about elk is available at the Michigan Department of Natural Resources website (http://www.michigan.gov/dnr/).
Afterwards, lead a class discussion asking students if they were surprised by any of their findings. Ask if any of these animals match their predictions from the chalk talk activity.

4. ELABORATE/EXTEND:

During the elaborate phase, students will focus more specifically on how cycles of mast production impact animal populations.

For an additional resource on mast-producing species and how they affect ecosystems, we recommend Nova’s “Population Ecology” module (http://www.pbs.org/wgbh/nova/nature/population-ecology.html ). This module explains what mast is and allows students to discover the impact a mast year has on population fluctuations of various organisms within an ecosystem. This module would be a good resource to view as a whole class. The module begins with a large acorn mast event in the fall and tracks population fluctuations in a handful of animal species for three subsequent seasons. You should explain to students that mice depend on acorn mast in oak forests as one of their primary sources of food. As a class, follow the white-footed mice throughout the simulation and read about how the mast event affected population levels. Afterwards, discuss how resource fluctuations in an ecosystem can have a major influence on the other organisms in an area.
5. EVALUATE:
The task for students in this section will be to demonstrate their understanding of the cause and effect relationship between acorn mast production and mouse population abundance.

Provide students with a copy of Figure 1 from Clotfelter et al. (2007, p. 497), which can be accessed at the following website (www.indiana.edu/~kettlab/pubs/Clotfelter2007b.pdf), and ask the following questions:

1. What information is shown on the x- and y-axes? Note that mouse abundance is recorded in MNKA per hectare, or minimum number known alive. One hectare is the area of a 100m by 100m box, or 10,000m2.
2. In what year(s) was the acorn mast index, a relative measurement used to compare acorn mast production between years, at zero?
3. What years was the acorn mast index highest from 1980 to 1990?
4. During the same time interval, what years was mouse abundance highest?
5. Write a paragraph describing the relationship between acorn mast index and mouse abundance.
6. Write a paragraph describing how acorn mast index might affect the abundance of other wildlife in your study area.

CONCLUDING THOUGHTS
We hope this lesson will provide you with a way to get your class outdoors, to participate in citizen science, while covering important middle school science standards. Using the MI-MAST program will accomplish the dual goal of providing conservation biologists with important data across the state of Michigan and giving you data to work with, and add to, year after year. After you have performed this lesson once, you will have designated trees or shrubs in your MI-MAST data logs that you can continue to track in future years, something you could expand upon in subsequent years since you will have known locations for trees from your first year. Eventually, rather than using the figure provided in the evaluate section from Clotfelter et al. (2007) you could track mast production cycles in your own study sites. From there, the possible extensions and classroom investigations could lead in other directions. We encourage you to adapt this activity however you see fit to meet the needs of your specific classroom and content requirements.
REFERENCES


Establishing a Schoolyard Habitat

Invite wildlife to your school: How to achieve national certification as a schoolyard habitat

Jill Raisor Vivian Xiang

ABSTRACT

The following manuscript details how to nurture nature through the establishment of a Schoolyard Habitat certified by the National Wildlife Federation. Requirements for certification, an example of a habitat established with children, budget and funding opportunities, possible curricular connections as well as suggested alignment to Next Generation Science Standards are provided.

*A sincere thank you is extended to the undergraduate research assistant, children, and staff who participated in this study.

INTRODUCTION

Wildlife is difficult to experience within the constraints of a traditional playground. However, establishing a schoolyard habitat near the playground can provide multiple opportunities for children to learn about, and experience different types of wildlife. “To help reconnect today’s children to the outdoors, National Wildlife Federation assists schools in developing outdoor classrooms called Schoolyard Habitats®, where educators and students learn how to attract and support local wildlife. These schoolyard habitats become places where students not only learn about wildlife species and ecosystems, but also outdoor classrooms where they hone their academic skills and nurture their innate curiosity and creativity… The program focuses specifically on assisting school communities in the use of school grounds as learning sites for wildlife conservation and cross-curricular learning” (Schoolyard Habitats).

It is possible to create a schoolyard habitat and achieve certification as a National Wildlife Federation Certified Schoolyard Habitat while integrating the Next Generation Science Standards (NGSS) into emerging curriculum. This manuscript details the requirements for certification, describes an example of a habitat established with children, and possible curricular connections.

REQUIREMENTS FOR CERTIFICATION

In order for a schoolyard habitat to achieve certification from the National Wildlife Federation, certain requirements are necessary. There must be at least one (1) source of water, two (2) sources of cover or places to raise young, and three (3) sources of food. Additionally, the established habitat must be registered with the National Wildlife Federation and official certification plaques to display are available for purchase (National Wildlife Federation).

EXAMPLE HABITAT

In a facility accredited by the National Association for the Education of Young Children, a classroom of two-year-old children and staff were interested in reviving
their playground. The existing playground was a traditional play space with black tile for ground covering, a chain linked fence surrounding the area, a fabric awning for shade, and common playground toys such as a playhouse, several tricycles, a picnic table, and an outdoor kitchen play area. The staff was concerned about the lack of opportunities to interact with nature and natural spaces that were sensory stimulating for the children. Therefore, they searched for an opportunity to create a schoolyard habitat for the children utilizing the existing playground space and surrounding area. Funding for the project from an internal university grant source totaled $1,000.00.

With the available funds, the requirements to establish a schoolyard habitat were met through the purchasing of:

- One (1) water source
- Two (2) sources of cover/places to raise young
- Three (3) food sources

Decisions concerning what type of materials to purchase under each requirement were made in consultation with the children. A birdbath was easily accessible to find locally and an aesthetic addition to the space. The birdbath was placed in a space outside of the fenced playground yet still visible. The staff had conversations with the children to problem solve what should be done during the winter months when the water in the birdbath might freeze which led to an investigation of affordable heaters. Next, the children and staff decided to offer three sources of covering which were also places young wildlife could be raised. Milkweed and shrubbery were added as well as birdhouses. In addition, it was important to replace the existing fabric awning with a natural source of shade which resulted in wisteria crawling up lattice work which ultimately provided a source of covering for animals as well as a natural source of shade for the children. Then, the children and staff decided on five sources of food (although the requirement was three) which included birdfeeders and various seeds, hummingbird feeders and nectar, squirrel feeders and corn, as well as plant life for food with wisteria for butterflies and milkweed plant. In addition to the required items, binoculars were added for birdwatching, clipboards to record drawings and observations of nature, and a certification sign to proudly display the school’s dedication to wildlife conservation. See
Connections to science and math standards as well as cross curricular connections were abundant. Two focus points of curricular connections were plants and animals as described below.

**Plants.** Plants were measured and data such as growth and watering were charted. The amount of rain that fell on the habitat was measured. Utilizing the leaves from the plants, prints could have been made. The children used leaves to make prints of local flowers and then quilted the individual pieces of fabric together as a class quilt. A color wheel could also be created using some of the plants from the habitat. The children were able to document plant growth through representations of the various stages in a

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**CURRICULAR CONNECTIONS**

Connections to science and math standards as well as cross curricular connections were abundant. Two focus points of curricular connections were plants and animals as described below.

**Plants.** Plants were measured and data such as growth and watering were charted. The amount of rain that fell on the habitat was measured. Utilizing the leaves from the plants, prints could have been made. The children used leaves to make prints of local flowers and then quilted the individual pieces of fabric together as a class quilt. A color wheel could also be created using some of the plants from the habitat. The children were able to document plant growth through representations of the various stages in a

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**Supplies and Materials:**

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<th>Quantity</th>
<th>Description</th>
<th>Unit cost</th>
<th>Total</th>
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<tbody>
<tr>
<td>1)</td>
<td>2 Bird House</td>
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<td>2)</td>
<td>12 Binoculars</td>
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<td>19)</td>
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**One-Time Experiences Total:** $725.09

**On-Going Experiences Total:** $46.94

**Grand Total:** $772.03
plant’s life (i.e. seed, small sprout, and adult plant). These representations were created right next to the plant by having clipboards with paper readily available for the children to use. Some of the illustrations and prints could have been bound together in a book.

Animals. A unique way of bringing the habitat inside the classroom was through the integration of researching and creating a bird watching area. Research was conducted by the children and teachers on which birds might be attracted to the area as well as discovering the types of things those particular birds might enjoy. Replenishing bird seed and feed was a constant expense; however, it kept the visiting birds happy and returning. The bird watching area is also where the binoculars were available to the children. The children also tracked and charted the wildlife they spotted in and near the habitat.

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<tr>
<td>INTERDEPENDENT RELATIONSHIPS IN ECO SYSTEMS: ANIMALS, PLANTS, AND THEIR ENVIRONMENT</td>
</tr>
<tr>
<td>➢ Use a model to represent the relationship between the needs of different plants and animals (including humans) and the places they live.</td>
</tr>
<tr>
<td>➢ Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.</td>
</tr>
<tr>
<td>➢ Use observations to describe patterns of what plants and animals (including humans) need to survive.</td>
</tr>
<tr>
<td>✓ 2nd Grade</td>
</tr>
<tr>
<td>INTERDEPENDENT RELATIONSHIPS IN ECO SYSTEMS</td>
</tr>
<tr>
<td>➢ Plan and conduct an investigation to determine if plants need sunlight and water to grow.</td>
</tr>
<tr>
<td>➢ Develop a simple model that mimics the function of an animal in dispersing seeds or pollinating plants.</td>
</tr>
<tr>
<td>➢ Make observations of plants and animals to compare the diversity of life in different habitats.</td>
</tr>
<tr>
<td>✓ 3rd Grade</td>
</tr>
<tr>
<td>INTERDEPENDENT RELATIONSHIPS IN ECO SYSTEMS</td>
</tr>
<tr>
<td>➢ Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.</td>
</tr>
</tbody>
</table>

TABLE 1. NGSS ALIGNMENT

Standards Alignment. Through incorporating the above curriculum ideas, teachers are able to address the Next Generation Science Standards (NGSS) and, in particular, those cross subject areas. Table 1 summarizes possible alignment to the NGSS.

FUNDING SOURCES

If you are interested in establishing a schoolyard habitat, funding opportunities are available. The National Wildlife Federation, local community support, and creative means of locating supplies are all suggested (National Wildlife Federation). Local community organizations, businesses, and families could also be a source of support and funding.
WHAT WE LEARNED
Throughout the project, there are areas which should be taken into consideration and could be extended in future projects. Consider the on-going supplies, such as birdseed, which are needed for a habitat and arrange continuous funding. Coordinate volunteers to assist with the maintenance of the habitat. Some of the plants and shrubs grow quickly, so constant landscaping is necessary. Ensure that the materials and supplies purchased or grown to support the habitat are safe and durable for the age of children exploring the habitat. Finally, make a concerted effort to extend the outdoor learning, naturally occurring with the habitat, to the indoor classroom.

CONCLUSION
In conclusion, the establishment of a schoolyard habitat can be created within an existing playground space. It is possible to attract and support local wildlife. This space provides an opportunity for children and teachers to witness cross curricular connections while nurturing nature.

REFERENCES
Starchy Surveillance
Ashley Meyer, Hamilton Middle School, Debbie Herrington, Grand Valley State University, Stephen Rybczynski, Grand Valley State University

ABSTRACT:

Students start learning about photosynthesis in early grade school, yet it is a topic they still struggle with in college. Misconceptions and lack of a deep understanding of photosynthesis may result from a paucity of quality science labs that address photosynthesis using inquiry. A quick internet search reveals that although a number of photosynthesis lessons are widely available, very few engage students in activities that allow them to actively construct an understanding of the principles of photosynthesis. Rather, most are cookbook style confirmation labs. The lesson presented here requires students to answer fundamental questions underlying photosynthesis using data they collected. This yields a deeper understanding and aligns with NGSS as students conduct an investigation and then use evidence to support their claims and make connections to other science topics.

BACKGROUND:

There are a number of well-documented student misconceptions regarding photosynthesis. One of the most common is that plants get most of their food through their roots from the soil. Some students say this is the reason that plants need fertilizer (Barker 1995; Barman et al. 2006, Driver et al. 1994, Kose 2008, Russel, Netherwood, and Robinson 2004). Another misconception is that water is the primary growth material for plants because it is absorbed through the roots. Other studies show that students hold the misconception that minerals from the soil are food for plants and that they directly contribute to plant mass (Driver et al. 1994).

The activity described in this paper was designed to address each of these three common misconceptions. Students first look at six pictures of plants, some rooted in soil, others in water. They are asked to classify these plants based on how they grow. This activity helps provide evidence that soil cannot be a factor in contributing to a plant’s growth or mass. Next, students perform a starch test on leaves from plants that helps them recognize that sugar production only happens when light is present, which would not be the case if plants got their food through the roots. However, light is a form of energy not matter, and therefore cannot directly increase plant mass. Therefore, the plant mass must come from somewhere other than soil or the sun. We then discuss the reactions that involve water and carbon dioxide to produce glucose and how the sun provides the energy necessary to drive this reaction. After their investigation, students read about van Helmont’s seminal willow experiment, reinforcing that plant mass does not come from soil.

In addition to addressing common misconceptions, this activity integrates all three dimensions of the Next Generation Science Standards (NGSS), in particular focusing on the Cross Cutting Concept: Energy and Matter, the Science and Engineering Practice: Constructing Explanations and Designing Solutions, and the Disciplinary Core Ideas: LS2. Cycles of Matter and Energy Transfer in Ecosystems and PS3.D energy in chemical processes (NGSS Lead States, 2013). This alignment is described in more detail in Table 1.
**TABLE 1: NGSS ALIGNMENT OF LESSON**

<table>
<thead>
<tr>
<th>Standards</th>
<th>MS-LS1-6. Matter and Energy in Organisms and Ecosystems</th>
</tr>
</thead>
</table>

**Performance Expectation(s)**  
The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below.

**MS-LS-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and the flow of energy into and out of organisms.**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Name and NGSS code/citation</th>
<th>Specific Connections to Classroom Activity</th>
</tr>
</thead>
</table>
| Science and Engineering Practices | **Analyzing and Interpreting Data**  
  • Analyze and interpret data to provide evidence for phenomena (MS-LS2-1) | Students make observations and collect data to discover where the necessary energy to carry out photosynthesis comes from. |
|  | **Constructing Explanations and Designing Solutions**  
  • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-LS1-6) | Students interpret historical data to construct an explanation for where a plants’ mass comes from. Students explain what materials? are necessary for a plant to create its food, in addition to constructing an explanation regarding where a plant’s mass comes from. |
| Disciplinary Core Ideas | **LS1.C: Organization for Matter and Energy Flow in Organisms**  
  • Plants, algae (including phytoplankton), and many microorganisms use the energy from the light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. (MS-LS1-6) | Students are shown that plants need sunlight to create sugar. Students investigate starch versus baking soda to discover the difference between the presence of starch and no starch. Students conduct an experiment to explore the role of light in formation of starch. |
|  | **PS3.D: Energy in Chemical Processes and Everyday Life**  
  • The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. (secondary to MS-LS1-6) | Students discover the light energy from the sun is turned into chemical energy for the plant by the process of photosynthesis. |
| Crosscutting Concept(s) | **Energy and Matter:**  
  • Within a natural system, the transfer of energy drives the motion and/or cycling of matter. (MS-LS1-6) | During activity and post-activity discussions allow students to explicitly reflect on the data collected throughout the lab and its meaning. |

Connections to Nature of Science (when appropriate):  

**Science Knowledge is Based on Empirical Evidence**  
Science knowledge is based upon logical connections between evidence and explanation. (MS-LS1-6).
ACTIVITY DESIGN:
After completing this lab, the student will be able to (1) identify the source of food for plants, (2) explain why light is important for plants, and (3) describe the importance of photosynthesis in plant growth. Materials required are found in Table 2 including Coleus plant (Figure 1 and 2).

TABLE 2: MATERIALS AND QUANTITIES NEEDED FOR STARCHY SURVEILLANCE LAB

<table>
<thead>
<tr>
<th>Material Needed</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coleus Plant (Figure 1 and 2) kept in dark</td>
<td>1-2 per class</td>
</tr>
<tr>
<td>Coleus Plant (Figure 1 and 2) kept in light</td>
<td>1-2 per class</td>
</tr>
<tr>
<td>Baking soda</td>
<td>1 box for serves 6 sections of 30 kids</td>
</tr>
<tr>
<td>cornstarch</td>
<td>1 box serves 6 sections of 30 kids</td>
</tr>
<tr>
<td>iodine</td>
<td>1 bottle serves several sections</td>
</tr>
<tr>
<td>Plant pictures (found in teacher guide (see online</td>
<td>1 set per group</td>
</tr>
<tr>
<td>supporting materials)</td>
<td></td>
</tr>
<tr>
<td>1000 mL beakers</td>
<td>6-8 per class</td>
</tr>
<tr>
<td>Hot plates</td>
<td>2 for the class (1 for ethanol, one for water)</td>
</tr>
<tr>
<td>Scoopulas</td>
<td>3-5 for the class</td>
</tr>
<tr>
<td>Petri Dishes</td>
<td>Two per group</td>
</tr>
<tr>
<td>Forceps</td>
<td>One per group</td>
</tr>
</tbody>
</table>

FIGURE 1: COLEUS PLANT. COLEUS IS FOUND WITH MANY DIFFERENT VARIATIONS TO LEAF SHAPE AND COLOR

FIGURE 2. COLEUS PLANTS COME IN MANY VARIETIES AND SOME HAVE MORE ANTHOCYANIN (PURPLE) PIGMENTATION THAN OTHERS. WHEN CHOOSING PLANTS TO USE IN THIS ACTIVITY, TRY TO SELECT ONES WITH A GOOD BALANCE OF CHLOROPHYLL AND ANTHOCYANIN.
This lab can be completed in two, sixty minute class periods, with the activity portions happening day one, and the discussion, extension, and conclusion of the lab done on day two. Complete teacher and student guides are found online at: www.gvsu.edu/targetinquiry (users are required to obtain a password to access the materials but registration is free). The online guides contain details about set-up, useful facilitation tips, typical student data, and handouts with answer keys.

**WHAT IS THE FOOD SOURCE FOR PLANTS? PRE-LAB**

Students are given several pictures of plants that are growing in different media (soil, water, vermiculite) and asked to classify the different plants based the pictures (see Figure 3). A class discussion at the conclusion of the pre-lab helps students recognize the things that plants have in common that might be contributing to their growth, as well as key differences. Students realize that not all plants need soil to grow, thus beginning to address the misconceptions that plants obtain their food (matter) from soil.

**What is the food source for plants?**

This question is the heart of the lab activity. To try and answer this question, students do a series of activities. After completing the pre-lab classification of pictures, students conduct an investigation where they test for the presence of sugar in plants that have been kept in the light versus in the dark for 48 hours. However, students need to recognize that starch is made up of sugars and that we can test for the presence of starch using iodine. Students need to wear eye protection during this activity. When they add a drop of iodine to each of the two unknown white powders (cornstarch and baking soda) the cornstarch turns black, whereas the baking soda just takes on the brown color of the iodine as shown in Figure 4. This prepares students to be introduced to the idea that starch is a made up of sugars and we can test for the presence of starch by using iodine.
Investigation-Starch test: Students then use this starch test to examine the leaves from different Coleus plants (one kept in the light, and another in the dark). Students sketch the leaves before and after testing for starch to track changes. However, in order to clearly see the results of the starch test, student must first remove the red/pink pigment (anthocyanins, carotenoids, xanthophylls, and other accessory pigments that absorb light) by boiling in water (Figure 5) and then remove the green pigment (chlorophyll) by boiling in ethanol (Figure 6). This step requires the use of a fume hood in addition to safety glasses and heat-protective gloves (https://www.nsta.org/docs/SafetyInTheScienceClassroom.pdf). After the pigments are removed, students can place a drop of iodine on each leaf to see which leaf (light or dark) has starch (Figure 7). We have made a video of this portion of the lesson (https://www.youtube.com/watch?v=KKjZOG6YswY) so that students without access to the required safety equipment can still engage with these concepts.

FIGURE 5: SHOWS A COLEUS LEAF WITH RED PIGMENT REMOVED AFTER BOILING IN WATER.
To analyze their data, students are asked to identify which plant showed the presence of starch and what the presence or absence of starch indicated (Table 4). From this, students could clearly see that only the leaf from the plant that was in the sunlight had starch. Thus, they were able to infer that plants need sunlight in order to produce sugar. This drives the point home that plant mass does not come from soil, but instead solar energy drives the reactions that form sugars (and therefore starches) that contribute to plant mass. A classroom discussion following data collection allows students the opportunity to reflect on what the presence and absence of starch meant and how it related to the data collected during the lab.

A relatively simple investigation like this really helps students to see that light is a key component to plants producing sugar. All of the students who completed this lab have been taught about photosynthesis before, yet after conducting this experiment we received numerous comments from students such as, "Wow, I really understand
photosynthesis now!", or “Why didn’t we do this lab when we learned about photosynthesis last year?”, or “I actually understand what the photosynthesis chemical equation means now!” This can be a great lab to run as an initial investigation into photosynthesis, or an introduction to a deeper discussion about photosynthesis to uncover and confront any naïve preconceptions students may have.

Where does the mass come from?: So far the activity has addressed the role of light, but not where the mass of a plant comes from. To complement the concepts that students discovered during the starch investigation, students are asked to analyze a scenario that describes Van Helmont’s Willow Experiment where he determined the change in mass of a willow plant and the soil in which it was growing from a juvenile plant to an adult one. Students calculate the amount of soil from when Van Helmont planted the Willow compared to when it has grown significantly. In doing this, students determine that the amount of soil changed very little which leads them to the conclusion that the plant’s mass cannot come from the soil because it has the same amount when it was a small plant and a large one (Table 5).

**WHAT DO STUDENTS GET OUT OF THIS?/DATA ANALYSIS**

This activity was used in four different sections of 15-30 8th grade students. Before the activity, students took a pretest with seven questions from the AAAS Assessment website (Life Science/Matter and Energy in Living Systems: ME004012, ME013008, ME029006, ME095004, ME095005, ME109003, ME112005). After conducting the activity, students answered those same questions as well as questions about their likes/dislikes, and frustrations from the experience. The actual questions and student data are presented in Table 3.

Comparing pre and post test scores, we found that this activity addresses misconceptions about photosynthesis, especially where plants get their mass and ingredients needed for photosynthesis to occur. Using a paired-samples t-test the mean overall score was found to increase significantly from 3.33 on the pre-test to 5.29
on the post-test \( t = -8.64, \text{d.f.} = 68, p < 0.001 \). The proportion of students answering each question on the post-test correctly was higher than the national data reported by AAAS (AAAS, 2015) for all questions (See Table 3). It is interesting to note that the scores were particularly high (65-90\%) on questions that addressed the misconceptions we targeted: 1) plants get most of their food through their roots from the soil, 2) water is the primary growth material for plants, and 3) minerals from the soil are food for plants and directly contribute to plant mass.

Student comments regarding their likes and dislikes were analyzed by the authors for themes using “Grounded Theory” (Corbin and Strauss, 1990). One common theme that emerged was that students liked the hands-on nature of this activity; that they actually got to complete the process on their own rather than reading about it or doing a demo. They also liked how the leaves changed colors, and that they got to work in small groups. The most common dislikes included the amount of reading and writing required to answer the questions in the activity and data analysis, and that they felt like they were rushed to complete the questions. (Note: This activity was completed in two 47 minute class periods).

**TABLE 5: GOING FURTHER: STUDENTS CALCULATIONS AND RESPONSES TO VAN HELMONT’S WILLOW EXPERIMENT**

<table>
<thead>
<tr>
<th>Question</th>
<th>Sample Student Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write down the weights (in your lab notebook) that van Helmont measured:</td>
<td>Initial weight of soil=200lbs, Initial weight of plant=5lbs</td>
</tr>
<tr>
<td>Initial weight of soil =</td>
<td>Final weight of soil=200.2lbs, Final weight of plant=169.3lbs</td>
</tr>
<tr>
<td>Initial weight of plant =</td>
<td>Change in weight of plant=164lbs</td>
</tr>
<tr>
<td>Final weight of soil =</td>
<td></td>
</tr>
<tr>
<td>Final weight of plant =</td>
<td></td>
</tr>
<tr>
<td>Change in weight of plant =</td>
<td></td>
</tr>
<tr>
<td>What question was van Helmont trying to answer?</td>
<td>How much mass can a willow grow with photosynthesis after 5 years?</td>
</tr>
<tr>
<td>Based on the information given, what is the conclusion from van Halmont’s Willow experiment?</td>
<td>The conclusion is: A willow can gain 164lbs over 5 years and the soil mass stays the same</td>
</tr>
<tr>
<td>In van Helmont’s experiment, light energy was necessary for the willow to gain mass. What happened to the light energy after it reached the willow plant? Write down the specific equation for photosynthesis and relate the equation to this question.</td>
<td>H2O + CO2 + sunlight=glucose + O2</td>
</tr>
<tr>
<td>Where did the new mass in the plant come from?</td>
<td>Sun gives the plant the ability to make food, and when you get food (or energy), you grow.</td>
</tr>
<tr>
<td>The Law of Conservation of energy states that energy can never be created or destroyed. Plants take light energy from the sun and uses it to produce sugar through the process of photosynthesis. Describe the specific of energy conversions that occur during this process.</td>
<td>Sunlight energy is converted to chemical energy for plants due to photosynthesis, and the plants save some of their energy for the winter</td>
</tr>
</tbody>
</table>
TABLE 3. PRE-POST TEST INSTRUMENT WITH CORRECT RESPONSES IN BOLD, AS WELL AS THE PROPORTION OF OUR STUDENTS THAT ANSWERED CORRECTLY AND THE PROPORTION OF STUDENTS THAT ANSWERED CORRECTLY IN THE DATA AAAS PUBLISHED.

<table>
<thead>
<tr>
<th>Question</th>
<th>Pre-test % correct</th>
<th>Post-test % correct</th>
<th>% correct from AAAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which of the following is food for a plant?</td>
<td>43%</td>
<td>87%</td>
<td>40% in grades 6-8; 39% in grades 9-12; 39% overall</td>
</tr>
<tr>
<td>(A) Sugars that a plant makes (B) Minerals that a plant takes in from the soil (C) Water that a plant takes in through its roots (D) Carbon Dioxide that a plant takes in through its leaves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which organisms store some of the molecules from food in their bodies to use later as a source of chemical energy and building materials?</td>
<td>52%</td>
<td>57%</td>
<td>51% in grades 6-8; 60% in grades 9-12, 54% overall</td>
</tr>
<tr>
<td>(A) Both plants and animals, (B) animals but not plants, (C) Plants but not animals (D) neither animals nor plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Where does the food that a plant needs from?</td>
<td>48%</td>
<td>87%</td>
<td>33% in grades 6-8; 40% in grades 9-12, 37% overall</td>
</tr>
<tr>
<td>(A) The food comes in from the soil through the plant’s roots (B) The food comes in from the air through the plant’s leaves (C) The plant makes its food from carbon dioxide (D) The plant makes its food from minerals and water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which of the following is TRUE about the sugar molecules in plants?</td>
<td>46%</td>
<td>88%</td>
<td>38% in grades 6-8, 42% in grades 9-12, 41% overall</td>
</tr>
<tr>
<td>(A) the sugar molecules are made by plants (B) The sugar molecules come from the soil (C) The sugar molecules are one of many sources of food for plants (D) The sugar molecules are made from molecules of water and minerals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which of the following is TRUE about the sugar molecules in plants?</td>
<td>59%</td>
<td>65%</td>
<td>31% in grades 6-8; 41% in grades 9-12, 39% overall</td>
</tr>
<tr>
<td>(A) The sugar molecules come from the soil (B) The sugar molecules are the result of a chemical reaction (C) The sugar molecules are one of many sources of food for plants (D) The sugar molecules are made from molecules of water and minerals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do plants use as food?</td>
<td>38%</td>
<td>90%</td>
<td>22% in grades 6-8, 27% in grades 9-12, 24% overall</td>
</tr>
<tr>
<td>(A) Plants use sugars that they make as food (B) Plants use substances that they take in from the soil as food (C) Plants use both sugars that they make and substances that they take in from the soil as food (D) Plants do not use sugars that they make or substances that they take in from the soil as food</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Which of the following statements is TRUE about the carbon dioxide that is used by plants?</td>
<td>45%</td>
<td>49%</td>
<td>41% in grades 6-8, 44% in grades 9-12, 43% overall</td>
</tr>
<tr>
<td>(A) It is combined with oxygen to make sugar molecules (B) it is absorbed through the roots of plants (C) It comes from air (D) it is food for plants</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
We want students to understand that science is a process and things do not always work out perfectly or cleanly every time. Yet, in the case of this activity, we found that when students do not get clear results it appears to negatively affect their understanding. The first time we tried this activity we used isopropanol because we did not have ethanol and our pilot trial with isopropanol worked fine. However, when the students used isopropanol, it gave mixed results and in some cases it did not remove the chlorophyll pigment from the leaves. While improvement in pre-test and post-test scores were observed regardless of the reagent used, there was greater improvement when the ethanol was used. We calculated mean relative gain (MRG) as [(pre-post)/pre] for students in the isopropanol sections (MRG= 0.58 ± 0.99) and ethanol sections (MRG= 1.31 ± 1.97), and found the difference between the two groups to be significant (t=-2.44, d.f.=61, p=0.02).

We also found that obtaining clear results led to less frustration for the students. In response to the question, “What was frustrating [about the lab]?” there were differences between isopropanol and ethanol sections. In the isopropanol sections, 16 of 33 (48%) respondents made comments that not getting the same/correct results was a problem while none of the respondents said this in the ethanol sections. These students said things like, “the results didn’t come out like they were supposed to” or “It was frustrating that not all the groups got the result”. Conversely, only 2 of 33 (6%) respondents in the isopropanol sections stated that “nothing was frustrating” compared to 12 of 36 (33%) in the ethanol sections. This suggests that while learning occurred regardless of the lab outcome, the students who obtained clear and interpretable results had a better experience.

CONCLUSION/PERSONAL REFLECTION:
Photosynthesis is a challenging concept for students and is covered across many grade level standards. Yet, students are often uninterested and struggle with the fundamental concepts. We believe this is because photosynthesis is generally taught out of context or without connection to other science concepts. By doing this activity students demonstrated an understanding that plants use the sugar that it produces from photosynthesis to grow and produce more leaves, stems, and roots, and that sunlight is the driving force for photosynthesis that forms the mass of the plant. Scaffolding students’ development of these concepts through a series of student-centered activities and investigations allows students to control their own learning and facilitates a deeper understanding of the basics of photosynthesis. This lab was taught to students as a science elective; however, some of these students also took 8th grade Earth Science with one of the authors. It was really rewarding to see students make connections between photosynthesis and concepts in Earth Science. For example, when we looked at regional buoy data and the Keeling Curve, students were able to explain daily and seasonal variations in data and correlate them to photosynthesis. They were able to look at annual CO\(^2\) data from the atmosphere that had been collected by local buoys and correlate the drop in CO\(^2\) during the summer to an increase in photosynthesis. While it was exciting to see that the pre and post data from this lab suggest that student growth occurs, seeing my students make these connections to other phenomena shows that a deeper understanding was gained from doing the Starchy Surveillance lab.
REFERENCES:


Author Guidelines

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Twice each year in the fall and spring, MSTA publishes a journal that reaches elementary, middle, and secondary classroom teachers, principals, and science educators. Why not share your ideas with your colleagues?

BEFORE YOU BEGIN
Review the current journal to get an idea of the types of articles that are published. We have two sections:

1. feature articles that deal with research, MEAP topics, or address a learning theory
2. classroom ideas that give classroom activities, usually in much the same format as the teachers uses in their own classroom.

Write clearly and concisely, organize your material logically, and use an active voice and conversational tone. Write about your firsthand experiences or your unique area of expertise and stress classroom applicability.

You must guarantee the originality of your work. Credit any other author’s ideas that you use or build on. Do not copy illustrations from textbooks. All illustrations must be copyright free.

Your manuscript length can be variable. We have published articles that range from 1-16 pages. On the title page provide each author’s name, current position, mailing address, e-mail address, home and work telephone numbers and fax number.

Cite only direct sources, and use the author-date reference style in the text. Bibliographies and resource lists should be alphabetized and limited to current, readily available items. Check the accuracy of your items carefully.

HOW TO SUBMIT
Email your article to Chris at (cchopp@kamsc.k12.mi.us) in Word format. If your article has specific formatting, please mail a printed hardcopy proof of your article to the editor for formatting reference. Note: If you do not supply a printed hardcopy proof for formatting reference, we can’t be held responsible for formatting errors or inconsistencies.

Photographs should be submitted electronically in high-resolution format (4” x 3”, 300 dpi). Students in lab must be shown following appropriate safety guidelines and wearing proper safety attire, including splash-proof goggles. Their faces should be visible, but they should not look directly at the camera. If the photo is used, a signed model release will be required of each student pictured.

CHECKLIST
☐ Author’s name, current position, mailing address, phone numbers are included with article.
☐ Written clearly and concisely with an introduction and conclusion.
☐ Stresses classroom applicability.
☐ References are complete.
☐ Photos show students following appropriate rules of safety.
☐ Two printed copies and a disk are mailed to the editor.