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STEM Career Exploration in Middle School Science Instruction

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Introduction

This article provides an example of how career exploration can be embedded in an NGSS-aligned middle school unit to help increase student awareness, build interest in STEM careers, and introduce role models and mentors for students. Students develop science identity by doing science and studying topics that are relevant to their lives. Through these types of activities, they begin to see themselves as someone who understands and does science. Also important is being recognized by others as someone who does and understands science (Ballard, Harris, and Dixon, 2018) and seeing examples of scientists who do not fit common stereotypes (Supporting and Advancing Geoscience Education at Two-Year Colleges (SAGE 2YC), 2021). Embedding explicit STEM career exploration into science instruction that supports students in building their STEM identity and connects activities to the home and community, can build a strong base for further STEM career interest. We discuss how curriculum materials and community engagement can support student and family discussion about careers and can be connected to other school activities and processes.

The Michigan Department of Education (MDE) has called for districts to take an active role in offering experiences that build knowledge and skills students need in order to be successful in postsecondary learning and careers. State legislation requires school districts to provide grade-level career development education based on the Michigan Career Development Model (MI CDM; Michigan Department of Education, 2018), with required targets at each identified grade band. Students in the younger middle school grade band, grades 4-6, are to engage in career awareness; activities that help students become familiar with a wide variety of careers. At the older middle school band, grades 7-8, students engage in career exploration to discover pathways and careers that align with their interests. High school students engage in career preparation; they refine their career goals, engage in the necessary educational preparation, and participate in advanced or real-world experiences that help link their career options and educational decisions.

Embedding career awareness and career exploration in science instruction also aligns with the recommendations of the Next Generation Science Standards (NGSS) Framework for K–12 Science Education (Framework). Appendix C of the Framework (NGSS Lead States, 2013) emphasizes that integrating science content, science and engineering practices, and crosscutting concepts will provide students the knowledge and skills they need in order to succeed in technical training programs and in 2- and 4-year college entry level science courses. Additionally, integrating careers in science instruction and curriculum material allows students to apply science practices similar to scientists and engineers, offering opportunities to explore and motivate interest in science careers.

Health in Our Hands (HiOH) Curriculum Materials

CREATE for STEM Institute at Michigan State University, in collaboration with the Health in Our Hands-Flint/Genesee Partnership, is funded by a Science Education Partnership Award (SEPA) of the National Institutes of Health to develop a new generation of learning materials. Health in Our Hands (HiOH) curriculum units (2021) connect the science classroom to the community to give youth and adults an understanding of modern genetics concepts. The units are:

- *NGSS-aligned* (NGSS Lead states, 2013) engaging learners in coherent learning goals that integrate disciplinary core ideas (DCIs), scientific and engineering practices (SEPs), and crosscutting concepts (CCCs) to enable learners to explain phenomena or solve problems and building and deepening genomic literacy by experiencing multiple phenomena across time.
- Project-based learning (Krajcik & Shin, 2014) where students, teachers and community members engage in collaborative activities to find solutions to a driving question related to critical public health issues.
- *Technology-rich*, including multiple simulations and online modeling to support instruction. A new simulation was developed for this curriculum with partners at the Concord Consortium that uses sand rats as a model for studying diabetes (Lee et al., 2018).
- *Culturally relevant*, connected to the community through the application of Community-based Participatory Research (CBPR) as a framework for development (Israel, 1998). HiOH partners with families and community members to address a critical public health issue bringing students' cultural background and family experience into the science class as a resource and asset for learning.

Embedding Health Career Exploration Activities in a STEM Unit

The HiOH curriculum materials (*Health in Our Hands, 2021*) embed biomedical research and health-related careers throughout the middle school units: Diabetes (*What controls my Health?*) and Substance Use Disorder (*How can looking for thrills make me miserable?*). In this article, we highlight the Diabetes Unit, in which students engage in case study activities to figure out why Monique is feeling unwell, understand the role of genetics and environment on Monique's condition, and offer recommendations for Monique to improve her health. Students apply knowledge and skills from studying Monique's case to their community and lives as they take on different career roles.

Explicit Links to Career-Awareness in Science and STEM Within the Curriculum Materials

Each learning set in the unit clearly states how the experiences connect to student lives, with a specific "Link to Career-Awareness" section (see Figure 1). This section of the curriculum materials identifies how career exploration is linked to the storyline, lists the careers that will be discussed in the learning set case studies, and offers suggestions for extending career awareness activities. Of Michigan's 17 Career Clusters, the Health in our Hands project provides opportunities to explore four: Education and Training; Health Science; Human Services; and Science, Technology, Engineering and Mathematics.

For example, the goal in Learning Set 1 is for students to recognize that the phenomenon is a health-related question. The Link to Career-Awareness section and the callout box help teachers to set the stage.

Figure I. Learning Set I Link to Career-Awareness in Science and STEM

- The Driving Question Board is similar to a diagnosis chart used in health-related careers. Make the connection that doctors, for example, ask questions, collect data, and discuss ideas about diagnosis and plan the care with their patients and the health care team.
- Other careers related to diabetes include nurses, nutritionists, fitness coaches, health educators, lab technicians, phlebotomists.

Figure 2. Learning Set I Callout

Making connections to medical careers and health-related issues

Point out to students that people who work in the medical field ask patients many questions as they collect information for diagnosis and treatment. This will give students a purpose/motivation for generating questions.

Strategies for Career-Awareness in Science and STEM Within the Curriculum Materials

The curriculum materials use multiple strategies to introduce students to science and STEM careers.

- **Connecting SEPs (e.g. asking questions) and CCCs (e.g. cause and effect)** to the work of health care providers (e.g., Lesson Set 1 (LS1))
- **Using a case study or scenario to situate students' actions** in the role of a healthcare provider (e.g., lab technician, genetics counselor) to use SEPs (plan and carry out investigations and construct scientific explanation, etc.) and CCCs (patterns; e.g. LS2, LS3). Having students take on career roles introduces careers to students in a way that is not just talking "at them", but allows students to experience the work of those STEM people (i.e. genetics counselors in the diabetes curriculum).
- **Exploring the relevance of science class** to their lives and science teachers as STEM professionals (e.g. LS4)
- **Using online simulations** to act as biomedical researchers employing multiple SEPs (e.g., plan and carry out investigations, analyze data, etc.) and consider ethical issues in research (e.g., LS5)
- **Highlighting the importance of collaboration** in science and STEM work (e.g., LS6, LS8)
- **Meeting and interacting with STEM professionals** through a community action research project and communicating their findings and recommendations (e.g., LS8)

Table 1 summarizes how these strategies are used in each learning set to weave STEM careers into instruction. Each unit culminates in a community action research project and health summit during which students are able to meet face-to-face with health-related and STEM professionals. Each community action project includes a classroom interaction with an expert related to the topic who is interviewed or supports students' research. A career panel and mini workshops during the health summit allow students to ask questions and hear more about visitors' career trajectories.

Table I. Connecting Career-Awareness in Science and STEM with 3-Dimensional Science Instruction. HiOH Diabetes Unit

Learning Set	DCI	Practices	Cross Cutting Concepts	Link to Career-Awareness in Science and STEM
LS 1	**LS1.B Growth and Development of Organisms**	**Developing and using models** **Asking questions**	**Cause and effect**	Doctors, nurses, nutritionists, health care team
The teacher discusses that the Driving Question Board is similar to a diagnosis chart used in health-related careers and makes the connection that doctors, for example, ask questions, collect data, and discuss ideas about diagnosis and plan the care (e.g., cause and effect) with their patients and the health care team.				

<table>
<tr><td>LS 2</td><td>LS1.A: Structure and Function</td><td>Constructing explanations</td><td>System and system models</td><td>Lab technician
Health educator</td></tr>
<tr><td colspan="5">Students discuss medical and public health careers. Students take the role of lab technicians, helping Monique’s doctor figure out Monique’s health issue by performing a glucose tolerance test on simulated blood plasma samples and analyzing and interpreting data to determine if the person has diabetes, and an insulin test on simulated blood plasma samples to determine if the person has Type 1 or Type 2 diabetes. Students write a lab report to explain the results of Monique’s blood test. Students also take the role of health educators developing materials to explain diabetes to the public. Suggestions for additional resources include to contact families, local hospitals, health departments, or local resources for information and speakers with careers related to diabetes.</td></tr>
<tr><td>LS 3</td><td>LS3.A: Inheritance of Traits
LS3.B: Variation of Traits</td><td>Developing and using Models

Constructing explanations</td><td>Patterns

Cause and effect</td><td>Genetics counselor</td></tr>
<tr><td colspan="5">Students explore careers related to genetics. Monique wants to know more about what can cause diabetes to develop, how her family affects her development of diabetes, and why she is the only one in her family with diabetes. Students take the role of genetics counselor to answer questions about how diabetes runs in families. Suggestions for additional resources include sites for genomics outreach events and hands-on activities and information about careers in genetics counseling (National Society of Genetic Counselors (NSGC))</td></tr>
<tr><td>LS 4</td><td>LS1.B: Growth and Development of organism</td><td>Planning and carrying out investigations

Analyzing and interpreting data</td><td>Patterns

Cause and effect</td><td>Science teacher</td></tr>
<tr><td colspan="5">Students think about how what they do and learn in science class can be connected to their everyday lives and how science teachers are STEM professionals. Monique’s science teacher heard about Monique’s diabetes and thinks she can help her answer the question,“In addition to her inherited genes, what other factors are related to Monique’s diabetes?” Using an online simulation, students investigate the role of the environment on the growth and development of plants, and through sense making, transfer their understanding of plants to human health.</td></tr>
<tr><td>LS 5</td><td>LS1.B: Growth and Development of Organisms</td><td>Planning and carrying out investigations

Analyzing and interpreting data</td><td>Cause and effect</td><td>Biomedical researcher</td></tr>
<tr><td colspan="5">Students use a sand rat simulation to help Monique further understand how the interaction of genetics and the environment affects her diabetes and health. Students learn that biomedical researchers are scientists who study how the human body works and often use animal models to find</td></tr>
</table>

new ways to cure or treat disease by developing advanced diagnostic tools or medicines. Scientists ask questions about the natural world and try to answer their questions based on evidence. Students discuss that what they did in the learning set is similar to what scientists do: plan and carry out investigations, collect and analyze data (sometimes using simulations), and draw evidence-based conclusions. They consider ethical issues in animal research. There are instructions for teachers to introduce biomedical research: Ask students what they know about biomedical research as a career. Has anyone heard of the term biomedical research? What do you think it means? What might a biomedical researcher do? What do they research? Make a list of students' responses.				
LS 6	**LS1.B Growth and Development of Organisms**	**Using mathematics and computational thinking** **Engaging in argument from evidence**	**Scale, proportion, and quantity** **Cause and effect**	Nutritionist, dietician
Students act as nutritionists; they examine Monique's diet and help her make healthier food choices. Careers included in this learning set involve collecting data to diagnose health conditions, and identifying food and nutrition issues in communities that affect the health of the population.				
LS 7	**LS1.B Growth and Development of Organisms**	**Developing and using models** **Constructing explanations**	**Cause and effect**	Scientists
Students learn how scientists use models to represent and explain various phenomena and link together the models developed over the course of the previous learning sets to explain the entire phenomenon. Based on the comprehensive model, students move from the question of "Why does Monique have diabetes?" to a general understanding of "What controls my health?" that can be applied to all people and health issues. Modeling and models help students understand that engaging in scientific investigations is a process in which scientists work together to revise their ideas during investigations.				
LS 8	**LS1.B Growth and Development of Organisms**	**Using models to predict** **Planning and carrying out investigations** **Analyzing and interpreting data** **Obtaining, evaluating, and communicating information**	**Cause and effect**	Community organizer, urban planner, public health researcher, elected officials, policy makers, college student

Starting with their comprehensive model, students form a research group to investigate a question about health issues in their community, and suggest solutions and potential actions in a presentation to peers and community members. As part of their research plan, students involve their families and an expert on their topics. As they plan their presentations, a set of "Motivation Coach" videos with messages from a mayor, physician, and professional basketball player encourage students as they prepare to communicate their findings. Students also watch a video about Monique's career plans in which she talks about how she wants to help others improve their health. Teachers invite community activists, educators, public health and urban planners, and researchers to celebrate students' accomplishments and listen to their recommendations for change. These relationships can help student researchers develop interest and confidence in subsequent formal and informal STEM learning and activism in the community.

The Health in Our Hands-Flint/Genesee Partnership (HiOH-FGP) Supporting Links to Career-Awareness in Science and STEM

A unique feature of HiOH is that partners from school districts, health-related organizations and community-based organizations have been involved in every phase of the HiOH project including curriculum design, classroom activities, community action projects, health summit planning and analysis and dissemination of results. Community activists lead the FGP, with membership open to all interested community members. Membership connects with regional STEM, place-based, and service-learning programs and initiatives. The vision of the partnership is "Youth empowered by science to improve health, advance careers, and promote community well-being."

An important role of the HiOH-FGP is to support students' projects. They identify experts from the community, volunteer as speakers and advisors to answer student questions, participate in interviews, and support student action. The HiOH-FGP, teachers and project staff organize district-wide or cross-district health summit events. The focus on careers includes community professionals to act as judges and to participate in career panels. In this way, students are invited as junior members into a community of educators and health activists who are concerned with the health and well-being of young people where they live.

Outcomes to Date

We have studied the outcomes of the STEM career component of the HiOH curriculum units through student surveys (S-STEM; Friday Institute, 2012); teacher surveys (T-STEM; Friday Institute, 2012); student, teacher, family, and judge Health Summit surveys; and observations of the Health Summits. Our major findings:

- **Students enjoy the social nature of sharing their research at the Health Summit, hearing about the research that the other classes conducted and discussing findings with judges and other students.** The feedback from the judges has also been positive with judges' commenting on students' openness and honesty during the presentations and how impressed they were with students' work "*div[ing] deeper into health topics that are concerning and that they should be aware of.*"
- **Students are interested in a variety of STEM careers but they don't know what it takes to get there.** Over one-half of students who completed the S-STEM in 2020 and in 2021 expressed interest in veterinary work or

medicine. Careers with the lowest expressed interest, which still had the endorsement of one-third of students, include physics, mathematics, energy and environmental science. A startling result is that although students expressed interest in STEM careers and confidence in their ability to achieve good grades, few reported that they expect to take advanced science or mathematics classes. In the 2020 cohort, over three-quarters of students (82%) reported that they planned to go to college. In 2021, the percentage of students who noted a plan for college was lower, 61% of students agreed that they planned to go to college. These data suggest a gap in middle school student understanding of how to achieve their career goals – that advanced mathematics and science courses and postsecondary education can help them on their path of achieving their career interests.

- **Students may not encounter STEM professionals on a regular basis in their community, nor have discussions about the roles of STEM professionals.** We find a lack of STEM career models among students. On the S-STEM survey, fewer than one-half of students reported that they knew adults who worked as engineers (49% in 2020; 40% in 2021), technicians (37% in 2020; 27% in 2021), mathematicians (28% in 2020; 22% in 2021), or scientists (26% in 2020; 14% in 2021).
- **Science teachers reported limited knowledge and ability to guide students' career exploration.** Of the 18 project teachers, 55% agreed or strongly agreed that they knew about current STEM careers, 36% that they knew where to find more about STEM careers and 27% where to direct students or parents to find information about STEM careers.

Future Directions to Enhance HiOH STEM Career Exploration

The HiOH team has started this process of embedding STEM career exploration in curriculum materials. The team has plans to strengthen the STEM career awareness and exploration activities to provide a more robust experience for students and teachers, and align efforts with other school and community initiatives.

- **Connect with other school activities/processes,** including planning with school counselors about further course planning and career exploration.
- **Strengthening career connections in the curriculum materials,** including explicit introductions to each career type; reflection points through exit tickets or journal reflections about the careers in the lessons; and a career sheet for each unit that lists all the careers that students learned about for further planning and family discussions.
- **Strengthen connections with community partners** to emphasize the career component and engage students with community members who could provide information and mentoring. For example, the team is exploring options for visits to the Genesee Career Institute.
- **Strengthen teacher professional development and support during implementation** to emphasize how student interests in career areas align with the curriculum materials and provide teachers with the information that they need to support students.
- **Further research students' STEM interests** by adding to student surveys additional STEM careers, including journalist, science writer, science communicator, and teacher.

Tips for Incorporating STEM Career Awareness in Your Instruction

Start small, pick one or two key career areas that connect with the phenomenon that students are studying or the practices or cross cutting concepts that are included in instruction.

- Consult with your guidance counselors about the tools and resources that they use with students; they might be able to provide you with information that you can share with students.
- Invite community members and families to record short videos or visit your classroom to talk about careers related to the topic of study.

- Send information home to families about the career discussions that you are having.
- Emphasize to students what it will take realistically to reach their career goals. Discuss the need to take advanced science and math to be successful in many of the STEM careers that they are interested in pursuing. “So plan now to get A’s in my class!”

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Introducing Young Children to Environmental Education Using Growing Up Wild

By: James McDonald
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Growing Up WILD is an early childhood education curriculum that builds on children's sense of wonder about nature and invites them to explore wildlife and the world around them. Through a wide range of activities and experiences, Growing Up WILD provides an early foundation for developing positive impressions about the natural world and lifelong social and academic skills. Why do science and environmental educators need a curriculum like this in the early years (Ages 3-7) of a child's education?

Nature Deficit Disorder

Richard Louv introduced the term "Nature-Deficit Disorder" in 2005 with the publication of his best-selling book, "Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder." He coined the phrase to serve as a description of the human costs of alienation from nature and it is not meant to be a medical diagnosis (although perhaps it should be). Louv's 2011 book, "The Nature Principle: Reconnecting with Life in a Virtual Age," extended the conversation to include adults, and explored this key question: "What could our lives and our children's lives be like if our days and nights were as immersed in nature as they are in technology?"

Although human beings have been urbanizing, and then moving indoors, since the introduction of agriculture, social and technological changes in the past three decades have accelerated that change. Among the reasons are the proliferation of electronic communications; poor urban planning and disappearing open space; increased street traffic; diminished importance of the natural world in public and private education; and parental fear magnified by news and entertainment media. An expanding body of scientific evidence suggests that nature-deficit disorder contributes to a diminished use of the senses, attention difficulties, conditions of obesity and higher rates of emotional and physical illnesses. Research also suggests the nature-deficit weakens ecological literacy and stewardship of the natural world. These problems are linked more broadly to what health care experts call the "epidemic of inactivity," and to a devaluing of independent play. Nonetheless, we believe that society's nature-deficit disorder can be reversed.

What can teachers and teacher educators do?

With the current expansion of universal preschool and transitional kindergarten and other early childhood programs, as well as national attention to children's health and issues of planetary sustainability, nature and environmental education is poised to play a critical role in preservice and inservice early childhood teacher education. In pursuing high-quality and accessible nature and environmental education for all teachers and children, though, teacher educators will need to redesign and create new courses and programs to strengthen conceptual knowledge and instructional expertise for novice and veteran teachers. As co-editors of this special section, we are pleased to present three articles that deepen and expand our understanding of how early childhood teacher educators can envision and implement high-quality, innovative nature and environmental education.

First, environmental education remains a relatively new field and curricular emphasis, and early childhood teacher educators have the task of learning the relevant research, policy and practice. This necessitates a measure of professional development at the teacher-education level as well as additional research into this process. Second, since early childhood teacher-education programs typically cover a great deal of curricular ground, nature and environmental education are often not prioritized in required course offerings or even as course electives.

This factor might involve both curricular and programmatic restructuring. Third, given the increasing variety of early childhood settings in terms of structure, curriculum, and expectations, teacher educators face the challenge of designing nature and environmental courses and practice for settings as diverse as small family child care in a home to large urban preschools.

There is growing evidence that, despite potential challenges, the need for teachers to integrate nature and environmental studies into their curriculum is essential. At a most basic level, we know that time in nature positively impacts a whole host of factors that impact educational outcomes, from stress levels to creativity to interest in science (Faber & Kuo, 2006; Louv, 2007; Wells & Evans, 2003). At a cognitive level, research has made clear that rich content knowledge is a precursor to the acquisition and retention of abstract reasoning (Duschl, Schweingruber, & Shouse, 2007; Metz, 2008). Current cognitive research shows that knowledge reasoning skills are domain specific, and so, in order for children to engage in deep reasoning about science, they need frequent firsthand experiences as well as structured opportunities for knowledge building and vocabulary development that are science specific (Gelman & Brenneman, 2004). By providing both unstructured and structured experiences in nature from an early age, children build an understanding of the natural world that allows them to engage in increasingly complex investigation and knowledge building over time. Further, in a time when access to nature is increasingly lacking in children's lives outside of school, making time and space for nature-based experiences as part of the school program has become more critical (White, 2004). Finally, early experiences with science and nature play a role in children's future interest in the sciences (Maltese & Tai, 2010). While early childhood classrooms are not primarily focused on future career development, it is nonetheless important to note the increase in equity that may come from providing early experiences in science and nature for all children.

How Can Growing Up WILD Address a Lack of Science and Environmental for Young Children?

According to the Association of Fish and Wildlife Agencies, the publisher of the curriculum, the activity guide, *Growing Up WILD: Exploring Nature with Young Children*:

- Is written especially for early childhood educators of children ages 3-7.
- Features 27 field-tested, hands-on, nature-based, ready-made thematic units and over 400 experiences in a full-color 11"x17" activity guide.
- Includes outdoor explorations, scientific inquiry, art projects, music and movement, conservation activities, reading and math connections and "Healthy Me" extensions.
- Involves social, emotional, physical, language and cognitive domains to help foster learning and development in all areas.
- Supports developmentally appropriate practice allowing children to learn at levels that are individually, socially and culturally appropriate.
- Is correlated to the National Association for the Education of Young Children (NAEYC) Standards and the Head Start Domains.

A young child's connection with nature can be as simple as sitting under a tree, listening to the chirping of crickets or planting a tree. Spending time in nature has many positive benefits. According to the Growing Up WILD guide, children who have opportunities to play and learn in nature are more likely to:

- Handle challenges and problems more capably.
- Act responsibly toward the earth and each other.
- Be more physically active and aware of nutrition, and less likely to be obese.
- Have a greater appreciation of the arts, music, history and literature.
- Choose science or a related field of careers.

Growing Up WILD helps connect children to the outdoors in a number of ways:

- Several of the 27 activities involve children directly exploring nature outdoors.
- All of the activities include a "Take Me Outside" section that offers specific suggestions for getting children active outdoors, with nature walks, physical games, and other activities.
- Many of the activities "Centers & Extensions" and "Home Connections" sections include ideas for furthering children's exploration outdoors.

How is Growing Up WILD Organized?

Growing Up WILD units are organized with the following sections to help integrate environmental education with other subjects in order to teach to the whole child:

Quick Facts: The Quick Facts in each activity help educators and learners build a knowledge base for further learning and exploration. Educators can launch into the activities knowing that significant prior knowledge is not required for success.

Wild Wonderful Words: These words are helpful for developing and understanding of the main topic or feature in each activity. In many cases, the words tie directly to the activity procedures, art projects, music and movement and other activity components.

Warm Up: Each activity includes a "Warm Up" to capture children's interest and attention while also helping the teacher determine children's current understanding of the concepts, attitudes, abilities and skill levels. Questions can be used effectively here to assess prior knowledge.

Ready, Set, Go: These step-by-step instructions break up the larger activity into several portions. Teachers may decide the pace at which they engage children in each step. In some cases, a class may complete one activity per day or perhaps stretch the activity over the course of a week or more.

Take Me Outside: To help fulfill children's needs for time outdoors and for connections with nature, this section provides ideas for learning experiences that are best suited for outdoors. Additional activity procedures, extensions, or field investigations may be conducted in the schoolyard, in a nearby park, or even on the sidewalk.

Healthy Me: This section suggests ways to encourage healthy habits in children and involves topics such as physical exercise, nutrition, personal hygiene or safety.

Helping Hands: Helping Hands activities suggest specific, practical ways to learn respect for all living things. Protecting a spider habitat, creating a simple bird habitat, learning wildlife observation etiquette or other age-appropriate conservation activities lay a foundation for a lifelong appreciation of the outdoors.

Mighty Math: This section provides suggestions for learning math concepts and practicing math skills that relate to the activity topic. These suggestions connect math to everyday life and give young children practice using math vocabulary.

Home Connections: Fun things parents, guardians, and children can do together to extend the learning at home. There are "Home Connections" cards in English and Spanish to copy and send home with children.

Music and Movement: Children enjoy singing their favorite songs, learning new ones, and making up their own, too. This section jump-starts vocabulary skills by providing lyrics related to each activity's topic and set to common childhood tunes. The movement section provides suggestions for movement related to each activity's theme. Movement can include dancing, performing actions which reinforce song lyrics or imitating how an animal moves.

Art Projects: Each activity includes "Art Projects" related to the activity topic. Some of these projects involve children in free expression, while others are more prescribed with a particular result in mind. Collectively, the projects use a wide variety of materials and art forms and help to promote children's creativity and skill. These projects can also be used by the teacher to assess student learning.

Centers and Extensions: This section includes suggestions of related activities that can be set up in stand-alone centers. Centers provide opportunities for individuals or small groups of students to learn through self-discovery and become more independent by allowing the child to direct his or her own exploration.

Snacks: Growing Up Wild would not be complete without suggestions for healthy snacks related to the activity's theme. Fruits, vegetables and whole grains are used whenever possible.

Conclusion

This resource fills a need for early childhood and elementary school educators who seek to involve their students in engaging science with an outdoor focus. I encourage you to examine this resource that takes a thematic approach to teaching the whole child.

About the Author

Jim McDonald is a Professor of Science Education at Central Michigan University in Mt. Pleasant, Michigan. He teaches both preservice teachers and graduate students at CMU. He is a certified facilitator for Project WILD, Project WET, and Project Learning Tree. He is the Past President of the Council for Elementary Science International, the elementary affiliate of the National Science Teaching Association.

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Integrating Digital Literacy in the Science Classroom

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Introduction

Science, technology, engineering, and mathematics (STEM) are in-demand occupations, yet many positions continue to go unfilled. The United States is projected to have about 1 million more STEM related jobs in the next decade (U.S. Bureau of Labor Statistics, 2019). Trends in eighth grade showed an increase in science achievement around the world from 2011-2015, yet the U.S. showed no increase or decrease (Martin, Mullis, Foy, & Hooper, 2016). Recently released data from international math and science assessments indicate that U.S. students continue to rank around the middle in science (Desilver, 2017). With science testing and scores continuing to be an issue in the United States, and as schools transform to embrace technology, we must ensure we find a balance between the excitement of new technology and the digital literacy and critical thinking skills students need to be successful. It's not enough to understand the content of science. While the content is vastly important, knowledge alone will not make a student successful.

Digital Literacy

While digital literacy is not a new term, its impact is often not fully comprehended. As technology constantly changes and improves, digital literacy must expand to include more than words and language (Greene, Yu, & Copeland, 2014; Mohammadyari & Singh, 2015). While many scholars have approached the topic of digital literacy skills, a lack of agreement on proficiencies needed to master digital literacy still exists (Hicks, Baleja, & Zhang, 2019). Technology is continuing to change our education system. Previously, students were limited to text and reading materials available at local schools or libraries. Today, the Internet provides an unlimited amount of resources that can be accessed anytime and anywhere with the aid of a mobile device.

While current students may appear to be competent Internet users, research indicates that many learners struggle to find, understand and integrate information from the Internet (Greene, Yu, & Copeland, 2014; Meyers, Erickson, & Small, 2013). Despite the ability to locate credible websites, students are rarely required to perform diligent searches for reliable information (Blikstad-Balas & Hvistendahl, 2013; Colwell, Hunt-Barron, & Reinkng, 2013; Greene, Yu, & Copeland, 2014), a skill that is necessary to be successful with STEM.

Digital Science Literacy

Science and literacy are parallel processes. Scientists, along with readers, writers, and communicators, activate prior knowledge, observe and ask questions, search for information, design investigations, take notes, sequence events, distinguish fact from opinion, make inferences, and communicate their findings (SciMathNM and the Minnesota Department of Education, 2018). Inquiry-based science requires students to seek answers about real-world phenomena. Students compare thoughts and communicate ideas through words and graphics. Literacy skills, therefore, help to extend and expand scientific reasoning (SciMathNM and the Minnesota Department of Education, 2018). As we continue to transition to a predominately digital society, literacy in science must also become digital. Digital learning provides content in a variety of modes including visual, text, audio, and multimedia. Being able to comprehend multimodal representations is important (Ng, 2012) due to the abstract nature of many scientific concepts. While there are many variances in the definition of digital literacy, examples generally require students to think critically, solve problems, and perform difficult tasks, all of which are also necessary scientific skills (Marty, et al., 2013). Between the Common Core State Standards and Next Generation Science Standards (NGSS), literacy has become a focal point. Common Core standards require students to translate qualitative data into visual forms

(Common Core State Standards Initiative, 2015). Unfortunately, little guidance is given on how to achieve digital literacy in science. Students need guidance on how to find accurate and reliable sources of scientific information, whether it is for a quick homework assignment or a long-term science project. The skills needed to sift through stories, differentiate fact from opinion, and synthesize data to communicate scientific ideas are not learned from everyday use of social media (Havlik, 2014). These skills need to be taught. Digital literacy is more than just integrating media into a lesson plan. It is about empowering students to interpret and make informed decisions from digital resources, while also effectively producing digital content.

Examples of Integrating Digital Literacy and Critical Thinking

As technology advances, literacy skills are still present but they may be expressed in more unconventional ways. Students can use mobile devices to document scientific experiences, take notes through a variety of apps and websites, or record experiments through pictures, videos, and sound (Yang, 2014). These videos or screencasts could then be shared at a science fair or online forum, giving family, friends, and community members a deeper look into the successes and struggles the student faced. Instructors may have students complete a digital scavenger hunt as part of the research process, or research and share information in a multimedia format (Yang, 2014). Students can create infographics of scientific findings or share ideas and scientific questions using a Pinterest board.

The Next Generation Science Standards encourage more writing in science classrooms and collaborative, peer feedback (NGSS Lead States, 2013). Blogging is one strategy where students can read and write digitally both for personal and educational uses. Reading other students' blogs has shown to be helpful in a learning environment, providing exposure to multiple perspectives (Ellison & Wu, 2008). Students can extend their learning opportunities through blogs and gain perspectives from others beyond their classroom. Numerous scientists and journalists have turned to social media to communicate their research ideas, so why can't educators do the same? Many informal, online forums such as Twitter, YouTube, and Facebook have been utilized for some of the most creative and engaging science conversations. Chris Hadfield, Canadian astronaut and Commander of Expedition 35, tweeted over 1.1 million followers from space (Havlik, 2014).

Students need literacy expectations with options. In a cross-curricular English and science project I created, students had literacy and engineering expectations for both classes. Students were given basic expectations but were allowed various options and alterations. Students were required to document their planning steps but could choose to share digital writings or presentations that included images or videos, along with text or audio explanations.

Reimaging Science Fairs

Science fairs have been around for decades. With the extensive curriculums, packed class time, and full family schedules, it often is difficult to fit in massive assignments like science projects. In reality, as we look at the Next Generation Science Standards, we should be focusing more on student-led projects, having students not only aim towards the end result but examine the processes involved as well. With the International Society for Technology Education (ISTE) standards for students, students must leverage technology to empower learning, construct knowledge, become innovative designers, develop computational thinking, be creative communicators, and become global collaborators (International Society for Technology Education, 2018). How then can we update the traditional science project and science fair to also help our students demonstrate digital literacy?

There is a great deal of reading and writing that goes into a science fair project. Students must choose a topic and project, often referencing the Internet for thoughts and ideas. Once a project is selected, reading and writing can occur through research, note-taking, and planning. Students document their progress and often finish with some form of a presentation. Finding simple ways to update these traditional steps with technology, no matter what access you have, is crucial. If you do not have time for a full-scale science project, have students complete mini-projects. Students could go through the planning and design steps without actually creating the project and testing it out, offering students the choice of how to digitally represent their work through a report, animation, or presentation.

Virtual Science Fair

One of the great additions of technology is the ability to share your work. There are numerous online science fairs, including Google Science Fair or the Internet Science and Technology Fair, where students can compete and interact with students beyond their local community. Educators can also create a local science fair providing an opportunity to share and present scientific findings with others through web pages or blogs. Beyond the traditional science fair skills, students will enhance their digital literacy skills through creating content in written, audio, and/or visual forms.

Maker fairs are becoming a big hit and are another option to reinvent the science fair. While still focusing on the science behind the project, maker fairs offer interactive, hands-on activities instead of simply displaying the project. Students can still demonstrate technical and literacy skills by displaying screencasts of ideas, progress, and products, and get others interested and involved by offering activities for them to explore.

Communication

Online communication is an essential part of digital literacy, providing numerous benefits to science learners. Students can interact with peers and instructors synchronously and asynchronously in ways that extend beyond the classroom (Ellison & Wu, 2008). Students need practice navigating the Internet to improve their communication skills, especially as research has connected digital literacy and search literacy (Greene, Yu, & Copeland, 2014). If information is not easy to find, students become frustrated and give up. Because students also rarely click on a website's links to other sources (Colwell, Hunt-Barron, & Reinkng, 2013), they often miss out on important information. With the overwhelming amount of information on the Internet, students become unmotivated and disengage from the learning experience (Greene, Yu, & Copeland, 2014). By offering more opportunities for students to practice these skills, they will continue to develop a better understanding of digital literacy competencies.

Chat spaces for students could be created to allow peer answering of questions. Using features in learning management systems that schools already utilize can make this option more manageable and feasible. Students who work in small groups will need to communicate with one another. Utilizing email or chat programs that are part of learning management systems or other apps can help streamline this process. Apps like Remind, which allow for quick reminders to be sent to a large group of students or parents could be used to recap information or prompt students about progress on a science project, creating another space to practice digital communication skills.

Mobile Devices

One of the biggest impacts of mobile devices on literacy and our science students comes from how communication occurs. Mobile devices open up an endless supply of tools to share experiences with others. Students can publish their projects online in a variety of formats through blogs and other websites. Mobile devices provide students with the ability to instantaneously share their ideas and experiences live, or to create their content and share at a later date (Yang, 2014). Sharples (2002) emphasized how learning should be conversational. Mobile technology can provide the pathway to accomplish this. In the past, learning mostly occurred in person. Mobile devices support the creation and sharing of ideas no matter if the students are sitting close together, far apart, or aren't even in the same location (Hsu, Hwang, & Chang, 2013).

With mobile devices being portable and affordable, learners are able to experience more one-to-one situations and are no longer restricted to a chair or computer lab (Gottwald, 2016). Mobile devices make it much easier for students to document the progress of science projects whether they are at home or in school. Numerous apps and features allow for students to quickly capture images, sound, and video, all of which they can later turn into a digital presentation and then share with others. Mobile devices also provide access to a wide range of reading materials (Trucano, 2014) from nearly any location. Even the simplest phones offer texting features, allowing for more literacy opportunities.

Conclusion

Science is a vital part of society and the numerous STEM career pathways that continue to grow. Both technology and literacy need to be integrated into our science courses at all levels. As our science standards focus more on engineering-based projects, we need to make sure our students can communicate utilizing technology. As technology continues to change and advance, educators must continue to look for ways to support their students in learning these new skills, while still engaging in the content.

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Asking Questions in Science: It's Where Instruction Begins

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

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world, inspired by the predictions of a model, theory, or findings from previous investigations, or they can be stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation. While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are the possible trade-offs? What evidence is necessary to determine which solution is best?

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

Questions are an essential part of science. What makes a good scientific question is that it can be answered by direct observations or with scientific tools. Examples of questions that are not scientific are based on values or opinions like what people believe is right or wrong, or beautiful or ugly.
Scientists may start with a broad question such as "What makes a seed grow?" Next, they break the question down into smaller questions: What are the essential factors necessary for seed germination? What factors are necessary for radish seed germination? They state the final question in a way that can be answered by investigation or experiment. A good scientific question is: "What effect does the pH of water have on radish seed germination?"

Tips on Asking Good Scientific Questions
1. Begin by asking several questions about a topic.
2. Eliminate questions that cannot be answered by direct observation or by gathering evidence.
3. Break broad questions into smaller questions that can be investigated one at a time.
4. Word questions in a way that allows them to be answered by an experiment.
Here are some good ways to begin scientific questions:
"What is the relationship between . . . ?"
"What factors cause . . . ?"
"What is the effect of . . . ?"

Productive Questions:
Many questions formulated by teachers have asked students to remember or revisit things that they supposedly learned. Students' ability to do this counted as success. Productive questions, however, have a different goal.

Productive questions purport to take a student forward in his or her thinking; they enable a teacher to provide scaffolding for students beginning to build their own understandings. The six types of questions—attention-focusing, measuring and counting, comparison, action, problem-posing, and reasoning (see sidebar, next page)—allow a teacher to meet students where they are and provide the kind of support needed at any given moment. These questions are not intended to be asked in any particular order, but rather to be responses to what the teacher hears and sees happening. The teacher's role becomes more of a monitor and facilitator as students become more actively involved and responsible for their own learning.

If strategically asked, productive questions keep students motivated and fruitful in their efforts. Interestingly, it is not only teachers who can contribute to this, students working successfully in groups can often be overheard asking their own productive questions.

Types of Productive Questions

Attention–focusing: Attention focusing questions call attention to significant details. For example, "What is it doing?", and "How does it feel?"

Measuring and Counting: Measuring and counting questions generate more precise information. For example, "How many/much/heavy?".

Comparison: "How are they alike/different?", is an example of a comparison question which fosters analysis and classification.

Action: "What if ....?", is usually how an action question would begin. Action questions generally encourage properties and events; exploration and encourages predictions.

Problem – posing: Problem posing questions support planning and trying solutions to problems. An example of such a question would be, "How could we...?"

Reasoning: Reasoning encourages reflection on experiences and construction of new ideas. "Why do you think so?", and "Can you explain that?" are a few examples.

Questions are an essential part of science. A good scientific question builds on what children already know and when answered, leads to other good questions. For a scientific question to be meaningful, however, it needs to be testable either by experimenting, measuring or observing.

Purposeful science inquiry happens when children are motivated to answer a question that matters to them. It involves them in collecting and analyzing data, developing explanations and solving problems about the world around them.

So how do you help students to develop a good scientific question?

- Ask your pupils to think of a topic that interests them and challenge them to come up with a list of questions.
- Guide them in the elimination of questions that cannot be answered either by direct observation or by gathering evidence.
- Help them to break broader questions such as "What makes a seed grow?" down into smaller questions that can be investigated one at time.
- Demonstrate how to word questions in a way that allows them to be answered by an experiment.

Here are some are some good ways to begin scientific questions:
o How does _________ effect_________ ?
o What is the effect of . . . ?
o What is the relationship between . . . ?

A testable question asks how one change (independent variable) influences something else (dependent variable). Check that your question can do this.

Students can answer their scientific questions in several ways

Observation Over Time
o What happens when you add a stack of sugar cubes to colored water?
o How does the weight of food change as it dries?
o How do our shadows change over the course of a day?

Pattern Seeking
o Is there a relationship between the size of the leaves on the tree and the amount of daylight underneath?
o Is there a relationship between the height of a person and how fast they can run?

Comparative and Fair Testing
o Which suntan cream protects you best from the sun?
o How does the size of the balloon affect the distance the buggy travels?
o Does the temperature of water affect how quickly it freezes?

The next step is to have a discussion on the results of an investigation. Here are some ideas for facilitating those discussions.

What are Science Talks?

Science is about exploring the natural world, but that means science is also about answering questions that we have about that world. One of the reasons that science can be dull to some students is the fact that the questions they were answering in science class aren't always the questions that students are wondering. Children are naturally curious. So, when you open up the classroom to their actual questions, it's amazing how much interest can surface.

A **science talk** is a discussion in a science classroom where students attempt to come up with an answer to a posed question, based on discussion and reasoning. These can be questions that the teacher comes up with, but some of the best science talks are where relevant questions are posed by students.

Science talks and discussions are a major part of what's called an **inquiry-based classroom**. This is a classroom where students try to figure out science questions and do experiments and activities to see science in action for themselves. Instead of being told everything, they can figure it out and explore in the same way scientists do.

While clearly, it's impossible for children to re-create hundreds of years of scientific discovery, with some guidance they can still figure out a lot on their own. If experiments are one side of the coin that is an inquiry-based classroom, science talks are the other.

How to Facilitate a Productive Discussion

So how do you run a science talk? What makes a talk productive and useful? In an ideal and productive science discussion, students will pose the ideas on what the answer to a question might be.

For example, they may be trying to figure out what causes the different phases of the moon. It's possible that a student in the class will know exactly what causes them. In that case, it is wise to ask them to allow the discussion to continue a little further before interjecting.

For those who don't have a full picture of what causes them, the discussion can be quite interesting. In figuring this out, students can pose their ideas, draw on a white board, or act out the positions of the sun, moon and earth. They can try to remember how often the earth spins on its axis, how often the moon orbits the earth, how often the earth orbits the sun, and try to see how everything fits together.

They can even test things out using flashlights and shadows. If you leave students to figure it out for themselves, you may find yourself in all kinds of interesting and heated discussions. This might be a resolved question in science, but to them it's a process of discovery.

Conclusion: How Can You Become a Better Questioner

In addition to knowing which questions to ask, there is also an art to delivery modes that engage a majority of students and get them thinking. Tobin, Tippins, and Gallard (1994) reviewed many research studies and found overwhelming evidence that giving appropriate wait time after asking questions can promote higher-level thinking and get more students involved in answering. Using the ideas from the research cited in this column, here are a few key steps toward becoming a better questioner.

- Consider your learning outcomes for the science lesson and think about the right kind of question to help you reach those outcomes.
- Practice asking productive questions that are tailored to promote higher levels of thinking.
- Create opportunities for students to ask their own scientific questions by asking more open- ended questions.
- Ask students to answer questions in their notebooks or small groups to give more students a chance to respond.
- Practice wait time and silence.

Adding these steps to your science teaching repertoire will lead to the kind of communication the Next Generation Science Standards (NGSS Lead States, 2013) recommend for inquiry-based science classrooms. Doing so will involve students in higher levels of thinking that have been shown to improve science learning (Treagust 2007).

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Using Michigan Geology to Teach Metamorphic Rocks

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Abstract
Metamorphic rocks are commonly taught with students studying randomly collected samples and identifying key characteristics. We designed a lesson using metamorphic rock samples from Michigan. The lab integrates hand samples, Google Earth, the Geologic Map of the Marquette Mineral District (Boyum, 1975), and the Bedrock Geologic Map of Michigan (Milstein, 1987) to identify rock types and spatial relationships. By using Michigan geology, students were able to infer past, dynamic tectonic environments. The lesson started with an introduction on rock types, their characteristics and metamorphic environments. Students also plotted pressure and temperature data and calculated absolute ages for some samples. The lesson concludes with a synthesis of their results.

Need to post on Weebly: complete lab handout, Pp, Marquette map, blank lab page

Article
Cross the bridge, get near Marquette, and Michigan's metamorphic riches are revealed. Rocks range from pillow basalts to quartzites and testify to the growth of North America nearly two billion years ago. Numerous road cuts make collecting easy and many guidebooks provide details of the area (Bornhorst and Klasner, 2008). Following the format of Mattox and Giovanni (2019), we describe a suite of samples that you can collect to teach the characteristics and significance of metamorphic rocks using samples collected in Michigan. As students examined the composition and texture of various samples they placed the rocks in either the foliated or nonfoliated group, estimated the metamorphic grade in which the rocks formed, and lastly, identified the rocks. The lab included plotting pressure and temperature data to determine tectonic setting and simple calculations of the radiometric ages of key rock units.

Many classroom samples may be perfect for teaching lithology, but they commonly have been collected randomly from different locations across the country and over the range of geologic time. In our Michigan-based approach, the samples and maps allowed students to reconstruct the geologic and tectonic history of our state.

This lesson is aligned to four standards in the Next Generation Science Standards (NGSS Lead States, 2013). MS-ESS3-1: Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy and groundwater resources are the result of past and current geoscience processes. By recognizing the environments and identifying the metamorphic rocks that are in Michigan, students are able to learn about the various deposits and quarries where resources were found. MS-ESS1-4: Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. By calculating absolute ages for many samples, students were able to see the changes in our region of North America throughout geologic time. Students also applied their knowledge on how these rocks formed at these certain times in Michigan's geologic history. MS-ESS2-3: Analyze and interpret data to provide evidence for phenomena on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. Students inferred that the Upper Peninsula was a convergent plate margin. HS ESS1-5: Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. The juxtaposition of rocks of different ages and origins indicate that two microplates were sutured together in the Marquette area.

Reviews of Michigan's metamorphic rocks and geologic history are provided by James (1955), Bornhorst and Brandt (2012), and Kesler (2019).

Our Approach

During our undergraduate training we rejoiced during field trips to classic locales near Marquette, such as Harvey Quarry, the intrusive structures at Wetmore Landing, the banded iron formations at Jasper Knob, the pillow lavas just west of town, or the Precambrian Kona Dolomite at Lindberg Quarry. After graduation, many of us joined professional organizations that offered guided field trips to different sites each year, such as Michigan Earth Science Teachers Association (https://www.mestarocks.org), Michigan Basin Geological Society (https://www.mbgs.org/), and the Michigan section of the American Institute of Professional Geologists (http://mi.aipg.org/). Lastly, numerous field trip guidebooks help locate new places of interest (Bornhorst and Klasner, 2008). Each field trip opportunity allowed us to collect and add new samples to be used in our classrooms. We found that our personal rock collections from Michigan held exceptional samples of foliated and nonfoliated metamorphic rocks. These samples provided the foundation for our new lab.

The format of our lab follows closely to that of Mattox and Giovanni (2019) for sedimentary rocks (Figure 1). Students collected information from hand samples, the geologic map for the Marquette Mineral District (Boyum, 1975), the Bedrock Geology of Michigan (Milstein, 1987) and Google Earth. Detailed geologic maps can also be used but are not required for the lab (see U.S. Geological Survey Detailed Maps below). The questions in the lab led students to make observations about the characteristics of the rock, including its texture, composition, conditions when it formed, and, finally, identification. Google Earth was used to plot the latitude and longitude of the sample location. Students could see the type of location and environment where the sample was collected (roadcut, lakeshore, forest, quarry). Next, they located the same location on a geologic map (Figure 2). They used the map legend to discover the rock unit and the geologic era of the sample.

Before running the lab, a lecture was used to introduce metamorphic rocks and the two major rock types (foliated and nonfoliated). Examples of the rock types and tectonic conditions under which the rocks formed were also described. Classification and identification keys from lab manuals were laminated for students to use with their hand samples. A PowerPoint presentation concluded the lab during which students were able to check their answers (Figure 3, see GVSU HSAG - Home (weebly.com) for the complete lab and PowerPoint).

The samples for the lab are not organized in chronological time nor spatially across Michigan. They are in the same order that they were collected. You may choose to assign your sample numbers in chronological order. But, if you add a new sample to your collection, you will need to renumber any samples that are younger and reprint the lab. Our collection consisted of six foliated rocks and five non foliated metamorphic rocks.

Running the Lab

Before running the lab, we organized all the materials including hand samples, maps, identification charts, and computers. We kept printed, color copies of the complete lab in a binder to reuse each year. We also printed out one, black and white, two-sided copy for each student. We posted a map of the Bedrock Geology of Michigan at the front of the class and printed several copies of the map of the Marquette Mineral District for students to share. Laptops with access to Google Earth were ready for each pair of students. We placed the hand samples in trays and arranged them by sample number. We had a total of 29 samples of 11 different rocks. Each location has three to four samples, enough to keep every student working with more than one sample of each rock.

We started with the full class working through two or three samples together. This included at least one foliated and one non-foliated metamorphic rock. This guided students on how to complete the lab and limited the number of general questions. We also demonstrated how to read the geologic map and use the identification charts. In addition, we showed students how to use Google Earth to locate where the samples were collected. Lastly, we showed how to identify the metamorphic grade of the sample and how to plot their data on a pressure/temperature plot (Figure 4).

The majority of the lab was dedicated to pairs of students exploring the samples on their own. Each pair of students took one sample to their table and answered the standard questions (Figure 1). The teacher circulated in the classroom to answer any questions. Some students got stuck on whether the sample is foliated or non-foliated. An answer key for our samples is provided so teachers have some guidance (see Figure 3 and the full PowerPoint at GVSU HSAG at https://gvsuhsag.weebly.com). We also provided a nearly incomplete template that can be used by students to record their observations.

We found it takes 4-5 hours to complete this lesson: one hour introduction on foliation, composition, and metamorphic environments; 2-3 hours with the samples, maps, and Google Earth; and one hour to synthesize their results.

Based on the samples that you have; your lab may look different from our model. If you have some of the same samples, you can use the lab pages that we prepared without any changes. If you have samples that we do not, we provide a blank lab page to use at the HSAG website.

Syntheses of Lab

After the student pairs have examined all the samples, we returned to the full class and used the PowerPoint to guide discussion (see supplement). This provided an opportunity for students to correct their work and ask questions. We included slides on the pressure and temperature of metamorphism, tectonics, and age calculations.

A defining characteristic of metamorphic rocks was the growth of new minerals that are stable under the higher pressures and temperatures. Attoh and Klasner (1989) used mineral equilibrium to calculate temperature and pressures at peak metamorphism. In the Watersmeet area of Wisconsin, the rocks formed at 7 kbar. In the Peavy area, near Dickinson County, Michigan, the rocks formed at 4 kbar. Lastly, near Republic, in Marquette County, the rocks formed at 2-3 kbar. The temperature estimate at all three locations was 600-650 C. In the lab, we provided the students with this basic data. They plotted the data and compared it to the mantle geotherm and inferred a plate tectonic setting. The Upper Peninsula was a convergent plate boundary about 1.88 billion years ago (Schultz and Cannon, 2007). Rocks were buried as deep as 20 km and at temperatures greater than 600 degrees C.

To reinforce their understanding of geologic time students calculated absolute ages for several rock units (see the last page of the lab). This constrained the timing of tectonism and the juxtaposition of microcontinents of different ages.

Extension

The lesson serves as a great jumping off point for the unequal distribution of Earth's resources. Banded iron formation was mined for iron ore for over 100 years (Merk, 2009) and is evidence for oxygenation of the ocean (Bornhorst and Brandt, 2012). Kona Dolomite from the Lindburgh Quarry is processed as stone and aggregate that is used in landscaping and the construction of roads, bridges and erosion barriers.

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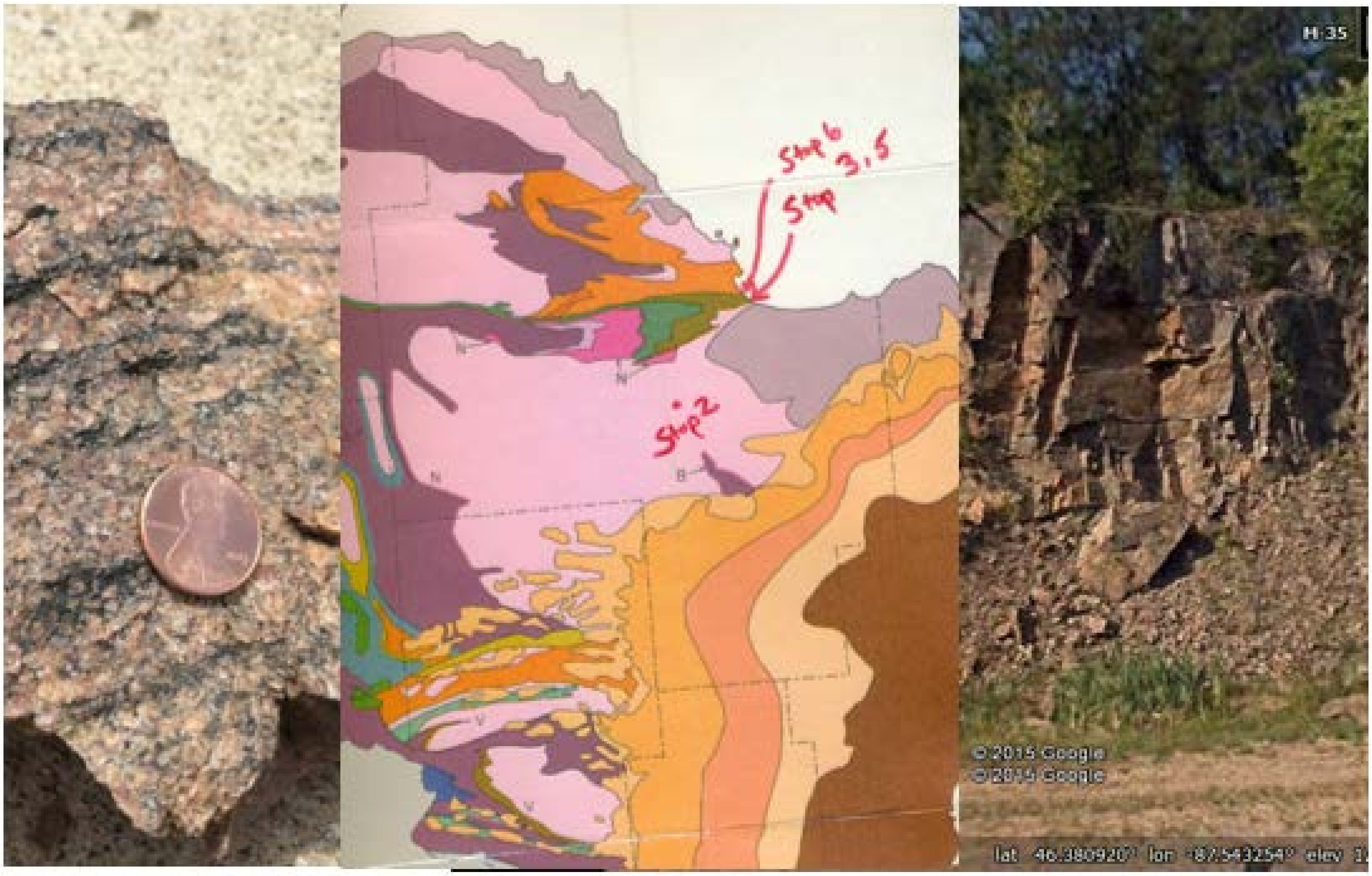
Figure 1. Format of the lab to guide students to investigate a metamorphic rock sample.

Metamorphic Rocks of Michigan Lab **Name:**

Stop 2: (46.3808,-87.5429); map: Republic; photo: street view



Is this sample foliated or nonfoliated? If foliation is present describe it. ______________________
____

What is the texture of this rock? ____

Identify individual minerals that you can see. ____
____

What do you think the type of parent mineral was? (i.e. sedimentary, igneous, metamorphic) Justify your answer.
____

What geologic unit is the sample from? Age? ____

Speculate on the pressure/temperature conditions this rock formed under. Justify your answer and state whether this means that the sample is a high, medium, or low grade metamorphic rock? ______________________
____
____

What geologic setting could have caused this metamorphism? Explain your reasoning. ______________________
____

What is the name of this metamorphic rock? ____

Figure 2. Location of metamorphic rock samples from the Marquette area on the map of Boyum (1975)

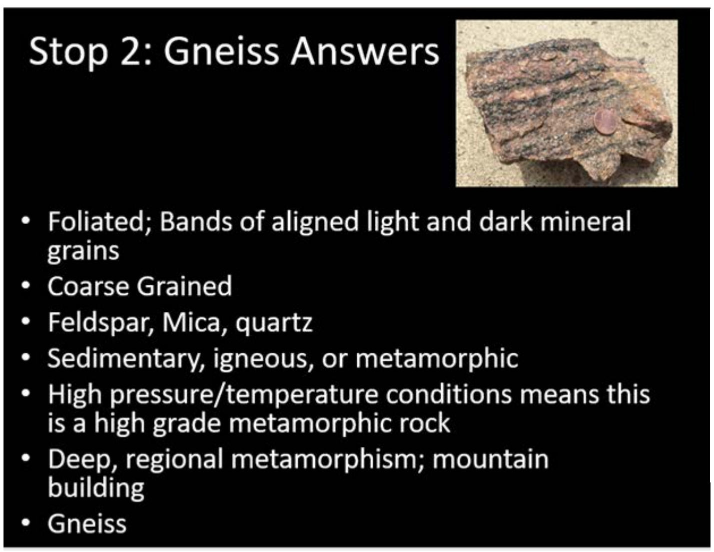


Figure 3. Example of the answer key provided in a PowerPoint in supplemental materials.

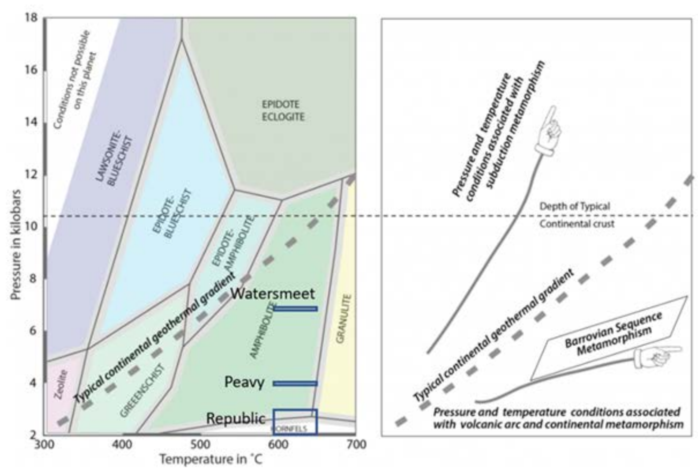


Figure 4. Location of metamorphic rock samples from the Marquette area based on their pressure and temperature. Barrovian metamorphism is associated with volcanic arcs and mountain building. Data from Attoh and Klasner (1989).

Interpreting the Geologic History of Michigan Using Cross-Sections

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Abstract

The general geologic history of Michigan can be constructed from interpretation of geologic cross-sections. We provide two classroom ready exercises. First, pairs of students interpret the geology of one of four panels, essentially "snapshots" in geology connected to a Michigan locale. Then, students interpret a single cross-section that includes the four panels and additional information. The single cross-section provides a broad overview of the complete geologic history of the state and can be connected to specific geologic locales.

Interpreting the geology of a large region is complex. In Michigan, our history started over 3 billion years ago (bya) and included almost every geologic process described in an introductory text book. To represent history, geologists commonly employ geologic cross-sections. Students are trained to apply Steno's Laws and cross-cutting relationships and to recognize and interpret the relevance of unconformities. We here provide two "simplified" cross-sections: Figure 1 is a set of four panels that can be used to construct specific stages of the overall geologic history of the state. Figure 2 is a single cross-section that, when interpreted correctly, summarizes 16 major geologic events that shaped Michigan.

How to Use

After students have practiced interpreting simple geologic cross-sections we focused on Michigan. We started by breaking the geologic history into four periods (Figure 1). We gave pairs of students one frame and projected the legend to the class. Each frame represented a place in Michigan and the cumulative results of local geologic events. We asked the students to write down the events in their frame and place them in order from oldest to youngest (Table 1). Then we asked pairs of students to share their interpretations, making corrections as needed. We wrapped up this part of the lesson by asking the students to speculate on the order of the frames from oldest to youngest.

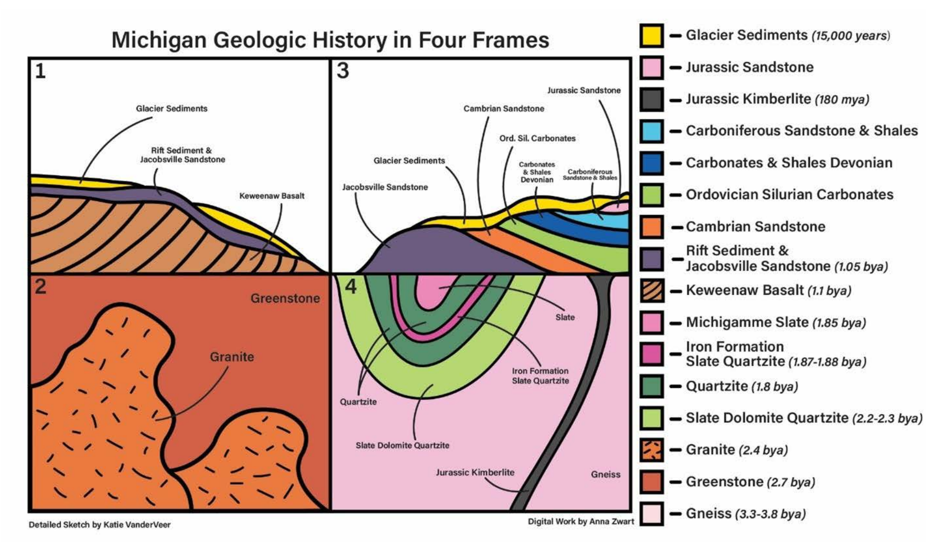
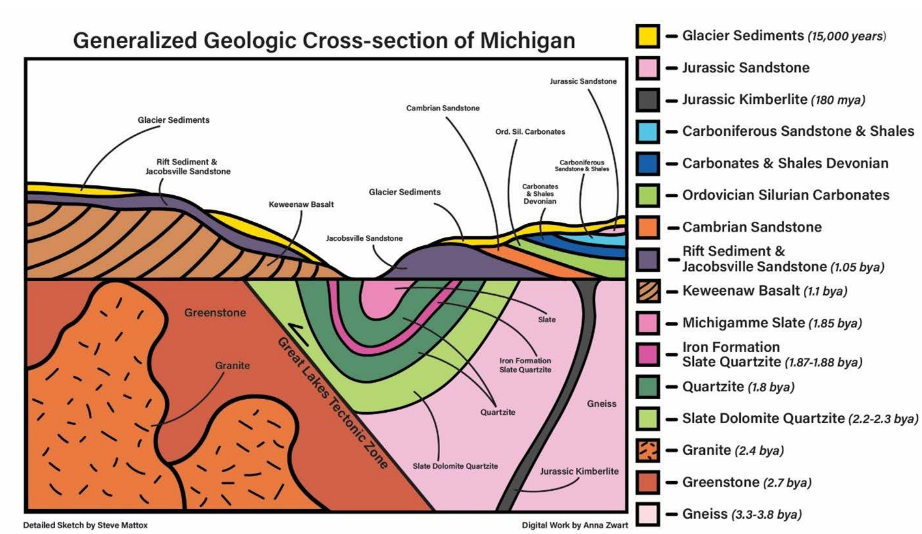


Figure 1. The geologic history of Michigan in four frames.

Table 1. Geologic events represented in four frames.

Frame	Events	Location
1	Eruption of Keweenawan basalt, folding of layers, erosion, deposition of rift sediment and Jacobsville Sandstone, erosion, depositional of glacial material	Keweenaw Peninsula
2	Eruption of basalt lava, intrusion of granite, low grade metamorphism of basalt to greenstone, post-glacial erosion, mostly by wind and rivers	Marquette area, north of M-45
3	Dposition of rift sediment and Jacobsville Sandstone, folding, erosion, deposition of Paleozoic sediments, folding to make Michigan Basin, erosion, depositional of glacial material, post-glacial erosion, mostly by wind and rivers	Edge to central Michigan Basin; Munising to Lansing
4	Metamorphism to make gneiss, erosion, deposition of sedimentary rocks; metamorphism of sedimentary rocks to make Slate, Dolomite, Quartzite, to Michigamme Slate, and folding to make Marquette Trough, and intrusion of Jurassic Kimberlite	Marquette area, south of M-45

Next, we introduced the generalized cross-section (Figure 2). The students commonly recognized their frame but there were additional relationships to interpret. First, the gneiss terrain is juxtaposed against the granite/greenstone terrain by a fault. This represents the collision of two smaller tectonic plates during the assembly of North America. Sims and others (1980) called this structure the Great Lakes Tectonic Zone. Second, the horizontal line that bisects the upper and lower parts of the cross-section represents an unconformity. This erosional surface developed after the folding of the rocks in the Marquette area and before the eruption of the basalts that make the Keweenaw Peninsula. Students needed to place these processes/events in their geologic summary.



We projected the generalized cross-section (Figure 2) to the class and asked the students to list the events, from oldest to youngest, that shaped the geologic history of Michigan. Table 2 lists these events.

Pros and Cons of the Simplified Cross-sections

On the positive side, we think our cross-sections can be interpreted by middle and high school students. The diagrams included a wide variety of geologic materials and features from across the state. A glance at the legends for the cross-sections indicates that we have included four types of metamorphic rocks, three kinds of igneous rocks, and five types of sedimentary rocks. Cole and others (this issue) and Mattox and Giovanni (2019) provided suggestions about teaching Michigan rocks.

On the negative side, some features are only partially shown or omitted. For example, the broad syncline of basalts from the Keweenawan Peninsula to Isle Royale is not complete. Likewise, the double syncline of the Michigan Basin is only shown in part. Cross-sections that include these features can be found in Schaetzl, Darden, and Brandt (2006). Some of our favorite rock units, like the Sudbury Impact Breccia are not shown because to the granularity of the scale that we chose. Although we include banded-iron formation, other economic units, such as copper mineralization, bedrock aquifers, and sand and gravel deposits are not emphasized. Some unconformities are disconformities and don't show in simple cross-sections. We also lumped the Paleozoic rocks by their age and general rock types. Lastly, the cross-sections are not to scale but exaggerate some features, such as the Marquette Trough, and downplay others, the Michigan Basin.

Table 2. List of major geologic events in Michigan.

1. Oldest: Metamorphism to make 3.3-3.8 bya gneiss
2. Eruption and metamorphism to make greenstone at ~2.7 bya
3. Intrusion of granite into greenstone
4. Erosion to bring metamorphic rocks to surface
5. Deposition of Slate Dolomite Quartzite to Michigamme Slate at 1.88 bya (and formation of an unconformity)
6. Folding of Michigamme Slate as gneiss terrain collides with granite-greenstone terrain along the GLTZ (Great Lakes Tectonic Zone) = Penokean Orogeny
7. Erosion
8. Eruption of Keweenawan basalts
9. Folding of Keweenawan basalts
10. Erosion and deposition of Jacobsville Sandstone and other sedimentary rocks in the Keweenawan rift
11. Deposition of Paleozoic sedimentary layers
12. Broad folding in the Michigan basin
13. Eruption of kimberlite
14. Erosion
15. Glaciation
16. Youngest: Erosion

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