FALL 2019
VOLUME 64.2

MSTA Journal

A PUBLICATION OF THE MICHIGAN SCIENCE TEACHERS ASSOCIATION

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Articles for publication in the MSTA Journal are invited on a contribution basis and are subject to editorial review. Please submit articles via email to Chris Chopp. Every attempt will be made to publish within a year after approval for publication.

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MICHIGAN SCIENCE TEACHERS ASSOCIATION

Super Saturday: The Benefits of a Weekend STEM Learning Program for Elementary Students

By Lauren Kenny, Pre-Service Teacher, Central Michigan University; Jim McDonald, Professor of Science Education, Central Michigan University

INTRODUCTION

The Great Explorations in Math and Science Center at Central Michigan University was started in 2005 by Dr. Jim McDonald and operated until its closing in 2019. The center was created to provide quality science and math professional development to in-service and pre-service teachers, as well as to provide quality science instruction to local elementary school students. As a part of the center, the Super Saturday Program was created. Modeled after the Super Saturday program that was already in place at Purdue University, the Super Saturday program at CMU was established to provide an extracurricular STEM educational experience for preschool through fifth grade students in the greater Mount Pleasant and Central Michigan region. The program took place twice a year, with one series of sessions occurring in October and one in February. The program ran for three consecutive weekends on Saturdays, with each class session lasting for three hours. In order to personalize the experience for the students, and to tailor the classes to be developmentally appropriate for all students, the student participants were split up into four different age appropriate classes depending on year in school: Preschool, kindergarten, first and second grade, and third through fifth grade. Classes were capped at a maximum of twenty students per class in order to provide a more personalized hands-on experience for the student participants.

Each of the four classes would focus on a different topic, and topics would change every semester, allowing a student to pass seamlessly through the grades without repeating a topic. This allowed for students to learn a wide range of topics over the course of their experience in the program. The curriculum for the classes was mostly themed around age appropriate GEMS units produced by the Lawrence Hall of Science, the science museum at the University of California, Berkeley ("GEMS", 2015). There were programs for grades preschool through eighth grade, allowing for a wide range of class options for each grade that could be perfectly adapted to best suit the instructional needs of each group of students. These units were created based on strong evidence-based teaching practices and came with supply kits that included all the materials that would be necessary to teach the unit successfully, as well as a teacher's guide that described all of the lessons and possible lesson extensions. In 2018, the program also began adapting lessons from the NSTA *Picture Perfect Science Lessons* series, especially in the preschool and kindergarten classes (Ansberry & Morgan, n.d.). These lessons also provided a strong evidence-based instructional approach to provide a well-rounded, integrated approach to science instruction for the youngest student participants. These lessons are based around the 5E instructional model which includes hands-on instruction that allows students to develop their own understanding of science concepts. Their use of high quality, captivating fiction and nonfiction children's literature helps to spark interest and helps children develop an understanding of key science concepts, a major goal of the Super Saturday program.

The classes were taught by college students at Central Michigan University. The majority of instructors were pre-service teachers who had been admitted into the Teacher Education program; however, the volunteer positions were open to any CMU student who was interested. Volunteer instructors worked in teams of two to four instructors per class in order to make the ratio between students and teachers smaller, thus allowing more personalized instruction for the student participants. At the beginning of each semester all instructors underwent a training session to best prepare them for teaching the students, and to become familiar with the unit they would be putting together and teaching. Each group of instructors then planned the lessons collaboratively and turned in the lessons to ensure quality giving them valuable learning experiences of how to teach math and science effectively.

LITERATURE REVIEW

There have been several studies conducted relating to the instruction of math and science to elementary aged students. Several programs around the country have been created similar to Super Saturday that focus on teaching math and science as an extracurricular. In their article "The effects of an afterschool STEM program on students' motivation and engagement", Chittum et. al discuss how student involvement in a voluntary afterschool and summer STEM Learning program for grades kindergarten through seventh helped to foster a greater appreciation for STEM subjects in the participants (Chittum, Jones, Akalin, & Schram, 2017). It also discusses how the students who participated valued STEM subjects higher than their peers who did not participate. It also showed that students who participated in the program showed less of a decline in motivation regarding STEM subjects come middle school than their peers who did not participate (Chittum et al, 2017).

Similar to the Super Saturday program, informal STEM enrichment programs are popping up all around the country. If done well, these informal programs have the power to have a tremendous impact in how students engage with the STEM field. The article "Benefits of Informal Learning Environments: A Focused Examination of STEM-based Program Environments" examines several of these different programs. Through their examination, the authors determined that considering the majority of a student's time learning is spent outside the classroom, it is incredibly important for informal learning environments to be productive and helpful for the students (Denson, Hailey, Stallworth, & Householder, 2015). The study found that teaching STEM subjects in informal contexts can help strengthen all students' knowledge of and attitudes towards STEM subjects by providing the students with exposure to new opportunities such as visiting college campuses, making the learning fun for the students, and building confidence by watching themselves and other's succeed (Denson et. al, 2015).

Many of these informal STEM enrichment programs are taking place as after school programs and are showing to be successful in garnering student interest towards the STEM field. In their article "STEM Related After-School Program Activities and Associated Outcomes on Student Learning" Sahin and his co-authors examined one of these programs that was occurring at a charter school in the southeastern United States (Sahin, Ayar, & Adiguzel, 2014). They looked into the benefits that this after-school program provided for its students, and more specifically the STEM skills that the students were able to obtain through their participation with the program. The study concluded that due to the emphasis on "open-ended and collaborative scientific investigations" that are a major part of STEM activities, students who participated in these STEM related after-school programs developed key skills such as “critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurialism, effective oral and written communication, accessing and analyzing data, and curiosity and imagination” (Sahin et al, 2014). These are all listed as skills necessary for success in the 21st century (Sahin et al, 2014). These students also showed an increased interest in STEM subjects in turn making them more likely to pursue interest in a STEM related career field in the future (Sahin et. all, 2014).

A common stereotype that emerges when considering the planning of STEM enrichment and who to focus on for the instruction of these STEM topics is that our youngest students do not need to be exposed to these genres. They are often perceived to be too difficult for our preschool or kindergarten children to handle. McClure challenges this belief in the article “More Than a Foundation: Young Children Are Capable STEM Learners”. This article challenges the misconception that STEM education is only beneficial for older students. It states that young children are born “natural scientists” and are born naturally inquisitive (McClure, 2017). This in turn provides evidence that young children are extremely capable of learning STEM subjects (McClure, 2017). The article also states how STEM subjects help teach skills such as critical thinking that are beneficial across several subject areas and are therefore important for children to learn at a young age (McClure, 2017).

While any productive extra exposure to STEM topics for students is beneficial, a group of researchers decided to measure some programs to see how beneficial these programs actually were at helping our students learn STEM topics. The researchers created a tool that they used to monitor and compare a wide variety of these informal programs (Shah et. all, 2018). Their results, detailed in the article “Improving STEM program quality in out of school time: Tool development and validation”, found that many informal STEM learning environments are lacking in the benefits that could be provided for students, and could benefit from the support of trained professionals and additional funding (Shah et. al, 2018). This showed that we are unfortunately not providing our students with the best possible quality instruction in many instances, showing that there is still work to be done in the field of STEM instruction.

It is important for STEM instruction to be engaging in order to be the most beneficial for students. An effective way to make STEM instruction engaging is to make it hands-on. This holds true both in informal and formal educational settings. A school in Louisiana adopted this method by introducing gardening into their school. In their article “Impact of Hands-on Science through School Gardening in Louisiana Public Elementary Schools”, researchers Leanna L. Smith and Carl E. Motsenbocker found that by adding on this hands-on gardening STEM enrichment to their curriculum, students were showing an increase in their test scores in science, despite the teachers not having any extra STEM professional development training (Smith et al, 2005).

RESEARCH

Data for this project was collected in two ways. An online survey was sent out in the fall of 2018 via email to the parents/ legal guardians of former Super Saturday student participants from the six most recent Super Saturday sessions, as well as posted on the Super Saturday Facebook page to reach parents or guardians from sessions further in the past. The survey consisted of ten questions meant to gauge the adults’ general opinion of the program.

Questions asked included how many Super Saturday sessions the student attended, why parents continued to sign their children up for the program, and what benefits the parents saw their children gain after attending the program. A total of 25 survey responses were received. The surveys also asked parents to rank their children's enthusiasm for attending the program, their interest in math and science after attending the program, and their enthusiasm for school in general after having participated in the program.

Five parents also volunteered to participate in a one-on-one in-person interview with myself about their children's involvement with the program. These interviews were meant to gauge in a more in-depth manner what the parents' thoughts and opinions were regarding the program. Parents were asked questions to learn more about their child's experiences with the program, what the parents believed the greatest benefit of the program was, and how they felt about the math and science instruction their students were receiving in school among other questions. These questions were meant to gain a more holistic, qualitative view of the program in a way that a survey cannot.

RESULTS

One of the first questions that was asked on the survey asked what grade the child was when they first attended the program. I was interested in this result due to the common misconception that younger children do not need as much exposure to STEM topics. As shown in Figure 1, our survey showed that 24% of respondents said their child started in preschool, 32% in kindergarten, 36% in first-second grade, and 8% in third-fifth grade. This means that of the respondents, 92% started their children in the program before they reached the third grade.

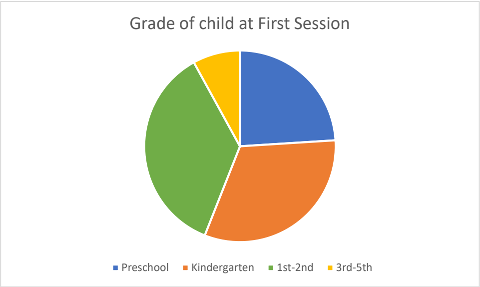

Figure 1

When asked to rank their child's enthusiasm about attending the program each week, results were generally positive. Results are shown in Figure 2. 80% of the parents surveyed answered a response of a 4 or 5 on the scale, indicating that their children showed high levels of enthusiasm towards attending the program. Less than 5% of respondents indicated a response of a 2 or lower.

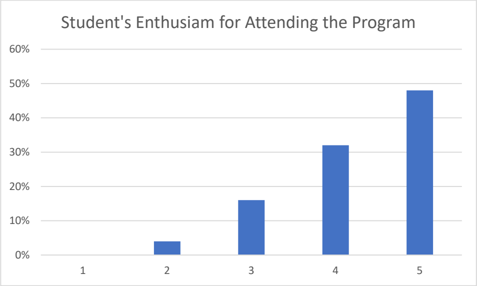

Figure 2

The survey also asked parents if they had noticed any changes in their children's interest towards math or science related topics after attending the program, with results shown in Figure 3. While no parents indicated that their children lost interest after attending, the majority felt as if their children either displayed no change in interest after attending the program or only noticed a slight increase in interest. Only 12% of respondents indicated that their child or children had a large increased interest.

This matched the results that I received during the interview process. The problem according to Parent C was that while their child thoroughly enjoyed the program, they did not see an increase in their child's interest towards math or science instruction at school. Instead the parent stated that Super Saturday has "made them more critical… because it increases their own awareness of what they prefer". The Super Saturday program has made Parent C's children more critical of the traditional methods how math and science is taught in schools by making them more aware of their own personal learning styles. The hands-on approach that Super Saturday utilizes in their instructional pedagogy is quite different from the traditional textbook and worksheet approach used in most schools and has proved to be an effective strategy towards reaching more students. Parent A stated that their child is "very artistic" and "enjoys learning but not in a textbook sit-down kind of way. He very much enjoys getting to make something such as the catapults or rocket launchers from the last session." Parent A's child's learning styles were more hands-on, and thus while they loved the STEM activities in Super Saturday, they became even more turned off to these subjects at school after discovering that there are other ways to learn this information.

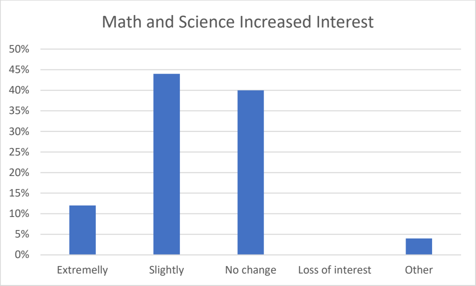

Figure 3

The Super Saturday program clearly had a large impact on the students and parents who participated. Shown in Figure 4, over 80% of parents surveyed indicated that they would recommend the program the others. This is important in today's society where parents are already stretched thin and there are many options for parents to send their children for enrichment programs.

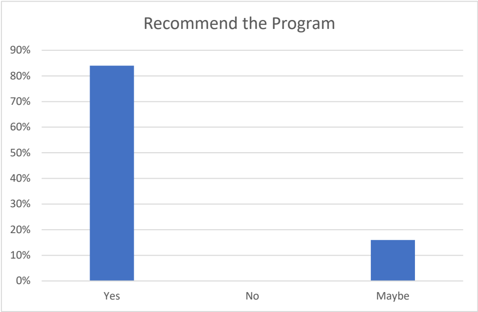

Figure 4

Finally, I was interested in learning more about how the student participants were doing in school regarding their math and science grades. If our program was providing successful STEM enrichment, the goal would be for the participant's grades in school to increase. As shown in Figure 5, the survey showed that almost 70% of participants had no significant reported change in their math or science grades after attending the program, while around 30% of parent's reported that they saw a minor improvement in their children's grades. This could be correlated to the lack of interest in math and science in school due to the traditional approach. One parent I interviewed with, Parent D, indicated that their child was doing particularly well in math and science, however it was "hard to say if it was caused by the experience". This parent went on to say that while drawing the exact correlations is difficult, they feel as if the program most likely played a role in the academic abilities of their child.

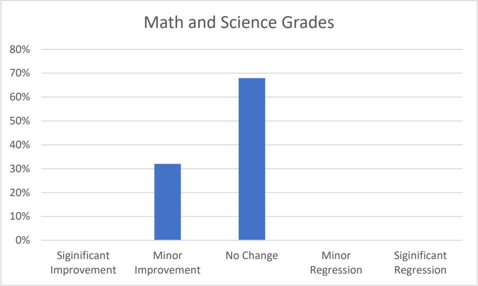

Figure 5

DISCUSSION

The results of this project did not turn out quite as I had expected. While I was happy to see that the program was perceived in a positive light among the parent respondents, there were several benefits of the program that I had not anticipated receiving, and some insight regarding STEM instruction in mainstream public schools.

One benefit that was echoed by several parents throughout the parent interviews was the importance of providing their children with the extra exposure to STEM concepts. Parent E mentioned that their favorite part of the program was the ability “to expose (their child) to science but not in the traditional classroom, just for fun” and to “give (them) a chance to see science outside of school in the real world.” Another parent, Parent C mentioned how they appreciated that Super Saturday gave them the opportunity to provide their children with “exposure to a developmentally appropriate level of STEM education provided by people who are positioned to do these things well”.

There were also several benefits that parents identified that I had not anticipated. One parent, Parent B, listed that a major benefit of the program was their child being exposed to women being active members in the STEM field. “Seeing college students, including women, run these programs is helpful in breaking down gender barriers”. With the STEM field being stereotyped as mainly male dominated, this parent enjoyed the ability to let his child see that women can play a major role in the field as well. This was an unintentional benefit as the majority of our instructors were teacher education majors, specifically elementary preservice teachers, which happens to be a predominately female dominated field. However, these student instructors were able to act as successful role models for the participants, showing students that women can be active members in STEM careers as well.

Another benefit a parent mentioned was providing the students the exposure to a college campus starting at a young age. Parent C enjoyed that the sessions were held on the university campus in university classrooms, allowing their children to see and feel a connection to college at a young age. They stated “A young person who is (exposed to) a college campus at a young age has a much higher chance of going to college. This program counts as an exposure to a university campus that can possibly point their later teen years in a positive direction.” By providing children as young as preschool the opportunity to come on a college campus for an educational activity, we are able to help the child build a positive connection with a college campus in turn possibly making them more interested or comfortable in attending a college when they reach their teen or young adult years. This comment goes along with one of the major benefits discussed in the article “Benefits of Informal Learning Environments: A Focused Examination of STEM-based Program Environments” (Denson et al, 2015). One of the benefits found in that study was that the students who participated in the STEM enrichment activity being researched were provided with the opportunity to go to college campuses (Denson et al, 2015). The students in that study noted how their experiences helped them to feel as if they belonged on the college campus, helping to make the idea of attending college more approachable (Denson et al, 2015). Despite the Super Saturday participants being much younger than the student’s in Denson’s study, by having them come on campus we are helping to make those connections early on in their lives.

Parents noted several more components of the program that they appreciated. Parent C indicated that they appreciated how the program provided their children with “a high quality, safe, and educational experience to go to on a weekend”. Parent C has also noticed their children exhibiting qualities they attribute directly back to the Super Saturday program, such as their kindergarten child developing a sense of quantities by “looking for objects to line up and calculate to discover the total number of”. They also believe the program has helped turn their children into “tiny engineers”, citing an example of their children making a volleyball net out of painter’s tape and paper. These skills that Parent C discusses noticing his children pick up include an awareness of data and an increase in curiosity and collaborative problem solving, correlating exactly with some of the 21st century skills that the article “STEM Related After-School Program Activities and Associated Outcomes on Student Learning” mentions informal STEM programs are capable of producing (Sahin et al, 2014).

Parent A appreciated how the program provided the participants with high quality math and science instruction for their children “that goes more in depth than the students receive in school.” Many parents indicated that the STEM instruction their children receive in school is either lackluster or nonexistent, so they appreciated the Super Saturday program for filling in the gaps that the public schools were missing. This trend of parents indicating that the math and science instruction being provided by the local elementary schools is lacking is alarming for our young students. This correlates with the thoughts McClure states in her article “More than a foundation: Young children are capable STEM learners”. She states that STEM is often left out of early childhood curriculum due to the stress on teachers of trying to add yet another mandatory instructional block to their schedule (McClure, 2017). By leaving out this instruction however we are providing a disservice to our youngest students and not setting them up for success as they age. This is echoed by Parent C who indicated that they believe their older child is struggling some with STEM subjects because “in the early years there wasn’t enough emphasis due to the major push for reading” and how this emphasis appears to be pushing STEM to the side despite “not having to be a prolific reader to be able to engage in STEM orientated activities”. It is clear that the parents surveyed for this study agree with McClure on the importance on young children being involved with STEM due to the result of 92% of parent respondents starting their child in the program prior to their child entering the third grade, as was shown in Figure 1.

Parent E indicated that they do not believe their child “receives enough science” as a part of the regular school day while Parent D believed that the children in school need to be working more hands-on with scientific equipment and that their child’s science instruction is not “sufficiently rigorous”. This information is unacceptable. Every parent interviewed indicated swiftly that their child did not receive the science education they would deem to be proper as a part of the regular school curriculum. Schools should not leave out an entire subject from the school day, especially in today’s STEM driven society. While informal STEM enrichment programs like Super Saturday can provide a great extension to students learning, they should be used as an extension and not as the main instruction. It is clear that there is still much work to be done in the field of STEM education.

CONCLUSION

After analyzing the results of both the surveys and parent interviews, it is clear that the Super Saturday program had a positive impact on the students who participated. It also became evident that math and science instruction at the elementary level is lacking. A common theme that emerged was that students enjoyed the active hands on nature of how math and science was presented during Super Saturday, therefore inadvertently causing a decrease in interest in these topics if and when they were presented at school in a more brick and mortar style.

FUTURE RESEARCH

If future research were to be conducted, it would be interesting to follow the student participants in a longitudinal study. By following students who participated in the Super Saturday program as an elementary school student throughout the rest of their educational careers, we could monitor their interest in STEM related fields of study and their grades in these subjects to see how they compare to their peers who did not attend the program to see if there is any measurable difference between the two across the student's entire educational career. Perhaps a more informative study would be to examine how math and science are taught in elementary school. With both being incredibly important subjects, especially in today's STEM focused society, it is crucial that these subjects are taught well to even our youngest students. Studies could be conducted that compare the traditional method of teaching STEM topics compared to using a more interactive approach similar to that used in the Super Saturday program. Researchers could also look into the concept of integrating STEM concepts with social studies and reading/literacy. With the common theme of STEM concepts being brushed to the side becoming more prevalent, integration could be a way to help push more STEM subjects back into the school curriculum, and thus would be important to examine.

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Guiding Ecological Investigations: Students Learn Science Practices and the Nature of Science

Christopher Dobson, Professor of Biology and Integrated Science, Biology Department, Grand Valley State University

INTRODUCTION

The research-based report, *A Framework for K-12 Science Education* (2012), proposed that students be engaged in **doing science** in the context of learning content. This corresponds to the science practices contained in the *Next Generation Science Standards* (2013) and the *Michigan K-12 Science Standards* (2015). The *Framework* also acknowledged the importance of students developing an understanding of the nature of science. The central thesis here is that having students conduct investigations is the best method for them to learn science practices and understand the nature of science. In this article I provide several examples from former students for illustrative purposes, describe the general format I use in my class, and discuss a few fundamental considerations to keep in mind when guiding students in ecological investigations. Having students conduct any type of scientific investigation will help them learn science practices and the nature of science. I specifically write about ecological investigations because I have guided students in these for 20 years. Although I teach college students, my hope is that some of the insight I have gained will transfer to classrooms at various grade levels.

EXAMPLES OF INVESTIGATIONS

I begin with three examples of investigations in which students learned science practices and the nature of science. All three were student driven in that they were conceived and designed by the students who conducted them, with my help of course. Each investigation culminated in a group PowerPoint presentation to the class and a written report submitted to me. One group looked at the difference in size of leaves in the canopies of beech and maple trees, a second at the abundance of algae under various stream conditions, and a third at the diversity of organisms living in two different habitats in a small pond. I do not expect readers of this article to be in a position to replicate any of these studies. Nor do I expect students at lower grade levels to be able to work as independently as college students. I simply want to use these examples to highlight how investigations help students learn science practices and the nature of science. Students in my ecology course for preservice teachers choose a topic to investigate based on initial observations they make on campus early in the semester. We are fortunate to have a variety of habitats to investigate on the Grand Valley State University Allendale campus, and this has led to many interesting studies.

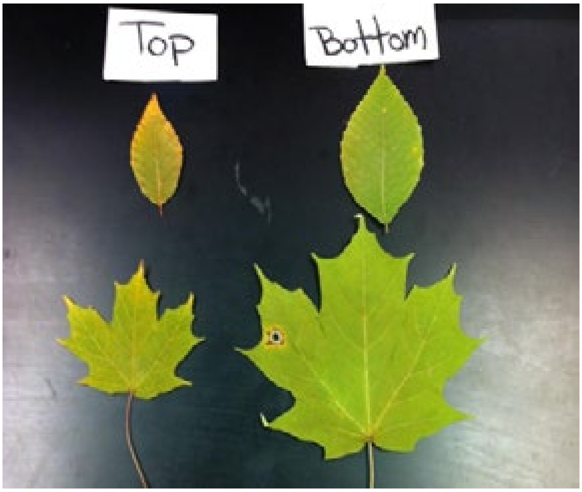
Beech and Maple Trees

In my first example, students noticed some variation in the size of leaves within individual beech and maple trees. After some Internet background research, they discovered that some plants produce leaves of different sizes. Leaves in direct sunlight (sun leaves) are smaller in area than leaves found in more shaded areas of the plant (shade leaves). The students found some trees adjacent to a bridge on campus, spanning a deep ravine, where they could access sun leaves in the upper canopy and also climb down below the bridge to access shade leaves in the lower canopy.

The specific question they asked was:

Is there a difference in the mean surface area of leaves in the upper and lower canopies?

Figure 1 shows the results of their investigation. In both cases, beech and maple trees, the leaves in the lower canopies were substantially larger. We were actually shocked by the difference in size. The corresponding leaves in Figure 1 are from the same trees!



	Upper Canopy	Lower Canopy
American Beech	24.7 cm^2	42.7 cm^2
Sugar Maple	35.4 cm^2	91.7 cm^2

Figure 1. Mean surface area of upper and lower canopy leaves in beech and maple trees.

The students performed ***t***-Tests and found the difference in size of the upper and lower canopy leaves to be **statistically significant** for both beech and maple. This highlights the use of statistical tests as an important aspect of scientific investigations. There will almost always be a "difference" in some mean measurement between two samples, for example upper and lower canopy leaves. Students need to gain an appreciation for how we determine if the difference is meaningful. For example, the mean surface areas for beech trees in Figure 1 are 24.7 and 42.7 cm^2. What if they were 24.7 and 28.2 cm^2? Students may conclude that there is a "difference" in the size of leaves, even though it is not likely a meaningful difference. This is why we use statistical tests. They allow us to determine when differences are meaningful (statistically significant). I suspect that many upper elementary and middle school students are capable of using simple statistical tests (e.g., ***t***-Tests) if their teachers show them how. Another option is for teachers to run the tests on data collected by students.

Stream Algae

In my second example, students became interested in the varying amount of algae growing in a small stream on campus. They noticed a large amount of algae in some portions of the stream and a low abundance in others. I asked them what conditions seemed to change along the stream. They said there was a difference in stream velocity in various sections of the stream and that rock abundance in the streambed varied, with some sections having no rocks at all. They decided to measure algal abundance in small plots similar to that being sampled by two middle school students in Figure 2.

They were unsure if stream velocity or rock abundance were influencing the amount of algae growing in various portions of the stream but became interested in answering the following two questions:

Is there a difference in the mean abundance among locations with slow, moderate, and fast velocities?

Is there a difference in the mean abundance among locations with zero, moderate, and high rock abundance?

Figure 2. Middle school students sampling stream algae.

Figure 3 shows the findings of their investigation. Although there was a difference in the mean abundance of algae in portions of the stream with different velocities, it was not statistically significant. There was a significant difference in the mean algal abundance in portions of the stream with varying rock abundances, with very rocky areas containing the most algae (Figure 3). The rocks act as a substrate on which algae attach. I wish I could bottle the students' excitement when their results showed such a clear but unexpected result; they expected stream velocity to be more influential than rock abundance.

Figure 3. Difference in mean algal abundance under various stream conditions.

Stream Velocity	Algal Abundance	Rock Abundance	Algal Abundance
Slow	179.4 cm^3	Zero	0.0 cm^3
Moderate	164.1 cm^3	Moderate	10.3 cm^3
Fast	278.9 cm^3	High	163.0 cm^3

Pond Habitats

A third group of students became interested in investigating a small pond on campus with two clearly distinct microhabitats. One habitat consisted of aquatic plants (***Sagitarria*** sp.) growing along one edge of the pond. The other habitat consisted of mats of algae floating throughout the middle of the pond. Figure 4 shows the actual pond as well as the students' drawing of the sampling locations for the two habitats. The students were interested in comparing the diversity of organisms (macroinvertebrates) in the two habitats.

The specific questions they asked were:

What is the species composition of each habitat?

What is the abundance of each species in each habitat?

Is there a difference in the mean number of organisms of a particular species in each habitat?

Figure 4. Two different pond habitats and sampling locations (A = algal mats, S = ***Sagitarria***).

Their findings are presented in Figure 5, along with a p-value indicating whether or not the difference between habitats was significant ($p \leq 0.05$). The students were thrilled to see the results of their investigation. With one exception, they found the same species in both habitats. Wolf spiders spun webs between the parts of ***Sagitarria*** plants that projected above the water. There were no similar structures to do this with on floating algal mats. Although both habitats contained the same species, there was a significant difference in the abundance of several of them. For example, aquatic worms and leeches were very abundant in the algal mats, but not in the ***Sagittaria*** habitat, and the difference was significant for both species. In their background research students discovered that the aquatic worms they identified are commonly found in clumped distributions in agal mats and are also prey for leeches! So the large abundance of both species in that habitat made sense. Another example worth highlighting involves the freshwater clams and Ramshorn snails. The snails preferred the ***Sagittaria***, and the difference in abundance was significant. Although the students found a larger abundance of clams in the algal mats, the difference was not significant. With a p-value of 0.071 the students concluded that it was approaching significance, and may have become so if they had more time to increase their sample size, a topic I will discuss later.

Figure 5. Mean number of organisms for each species in both pond habitats.

	Algal Mats	Sagittaria	
Species	Mean	Mean	p-value
Aquatic worms	25.5	2.0	*0.018
Boatman	2.3	6.0	0.142
Damselfly larva	5.8	3.3	0.369
Daphnia	11.3	18.0	0.084
Dragonfly larva	0.3	1.3	0.123
Freshwater clams	11.8	3.0	0.071
Freshwater leeches	8.0	1.0	*0.023
Ramshorn snails	3.5	7.5	*0.018
Various beetles	2.0	4.8	0.186
Water striders	0.8	3.8	*0.027
Wolf spiders	0.0	2.0	*0.016

SCIENCE PRACTICES AND THE NATURE OF SCIENCE

What the three investigations above had in common is that students engaged in all of the science practices (*Next Generation Science Standards* and *Michigan K-12 Science Standards*) to some degree and also developed a deeper understanding of a number of aspects of the nature of science (*Next Generation Science Standards*). Guiding students in ecological investigations is an ideal way to facilitate this.

Science Practices

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Nature of Science

1. Scientific investigations use a variety of methods
2. Scientific knowledge is based on empirical evidence
3. Scientific knowledge is open to revision in light of new evidence
4. Scientific models, laws, mechanisms, and theories explain natural phenomena
5. Science is a way of knowing
6. Scientific knowledge assumes an order and consistency in natural systems
7. Science is a human endeavor
8. Science addresses questions about the natural and material world

The students who studied tree leaves, stream algae, and pond habitats obviously asked questions, planned investigations, analyzed data, and used computational thinking. They also obtained and evaluated information in the background research they did on their topics. In their PowerPoint presentations and written reports they constructed explanations, engaged in argument from evidence, and communicated information. Obviously, conducting investigations allows students to experience science practices, but it also provides the opportunity for students to develop an authentic understanding of the nature of science. Watching the PowerPoint presentations of different groups in class shows students that different investigations use a variety of methods. Students really gain an appreciation of the need for evidence in science and how knowledge is open to revision based on new evidence. By conducting their own investigations, students come to see science as a way of knowing, and after struggling through the whole process, more appreciate science as a human endeavor.

GENERAL FORMAT OF INVESTIGATIONS

I wrote an article published in ***The Science Teacher*** (Dobson 2008) detailing the ecological investigations my students conduct, but here I describe the general format students follow:

1. Make observations
2. Ask questions
3. Design study
4. Data collection & analysis
5. Written report and group presentation

Students begin by making observations outside in natural areas on campus. At your school these initial observations could take place in a number of different outdoor areas, any place there are living organisms. Over a 3-hour period I encourage students to make "focused" observations, using all of their senses except taste. Safety is an issue here. I have students wash their hands when they get back to the classroom. I also scan the areas beforehand to make sure there are no plants (e.g., poison ivy) or animals (e.g., wasps) present that pose a threat to students.

Students work in groups of three or four, and I move among groups asking them to share what observations they have made. Over the course of the initial observation period, I begin asking what topics most interest them. Specifically, I want to know what questions they would like to answer. My role at this point is to help them select topics and related questions that I feel they will have success answering. A requirement of the investigation is that students answer questions based on **data they collect**, and not just look up answers to questions they have on the Internet. In the later stages of the observation period, when students are settling on their questions, I ask them to describe how they will attempt to answer them. This encourages students to be realistic about what questions they can answer and becomes the beginning of study design.

Throughout the course of designing their investigation, students look for background information on their topic in books and articles, and on reputable websites. I explain to students that they are not going to write a "book report" on their topic. They are looking for information that is related to their investigation. In the tree leaf study, for example, information on photosynthesis and leaf photosynthetic tissue was relevant. Information on tree life cycles or seed dispersal was not. I expect college students to review the primary literature (research-based studies in scientific journals), but at lower grade levels a teacher can provide appropriate books, magazines, and websites to students. Information students find helps them refine their questions and frame them based on what is already known about their topic. During the tree leaf investigation, students discovered the existence of sun and shade leaves in their background research and designed their study to determine if these existed in beech and maple trees.

Before students begin data collection, they submit a **written proposal** to me that includes 1) their questions, 2) how they will attempt to answer them, and 3) what they expect to find. These correspond to the various sections of the report they will write. Their questions will go in the *Introduction*, along with relevant background information, and the findings of other related studies. For this reason, I have students include as much relevant background information as they can in the first part of the proposal, citing references. The second portion of the proposal is obviously going to become the *Methods* section of the written report. The writing they do in the third part of the proposal on what they expect to find, will appear at the very end of the *Introduction* section of their report, as well as in the *Conclusion* section as they discuss how what they actually found was or was not what they expected.

Students also conduct a **preliminary data collection** prior to starting actual data collection for their project. Up to this point, what students thought they would do in their investigation was entirely untested, essentially just in their heads. Going outside and actually doing it often leads to modifications in study design. For example, after the preliminary data collection it may become apparent students cannot answer a particular question for some logistical reason but are able to ask another instead. Or they may find that there will not be enough time to complete what they had intended and are forced to limit the scope of their study. This is a valuable aspect of the investigations I have guided as students become better prepared to "hit the ground running" in actual data collection.

Students have three 3-hour blocks for data collection, and throughout this period I encourage students to keep making observations and keep "thinking" about what they are doing. I tell them it is better to make changes to their study design half way through data collection than it is to stick with what they had originally planned, if it turns out to be flawed or could be improved in some way. Data analysis occurs in the classroom, as I move from group to group helping them make sense of their data. As students begin preparing figures and tables for their report and presentation, I help them understand that tables are used to display results when the data themselves are important, while figures are used to illustrate a pattern in the data. Figure 5 shows the proper use of a table, where the actual values are important for the reader to see. A scatterplot graph with a trend line highlighting the relationship between two variables is an example of how a figure is used to illustrate a pattern. Figures can also include pictures of various organisms or structures students find (leaves in Figure 1), a map of their study area, or a visual representation of their sampling method (algal and pond sampling in Figures 2 and 4).

The written report that students submit contains the following sections: *Introduction*, *Methods*, *Results*, *Conclusion*, and *References*. Students also give a group PowerPoint presentation on their investigation to the rest of the class. It contains the same sections as their report, and they field questions from other students at the end of their 15-20 minute presentation. Having just completed their own investigations, classmates are generally eager to ask questions, some because they are genuinely interested in the topic, others because they want to make sure the study has been conducted fairly. As a teacher I find the engagement generated during student presentations to be very fulfilling. Instead of a report or

PowerPoint presentation, your students could make posters and transform the classroom into a mini science conference. I have also had groups give guided field walks where they took the class out to their study site to show them what they found.

My assessment of students occurs throughout their investigation, and is both informal (written proposals) and formal (written reports and presentations). I want students to acquire more sophisticated understandings and abilities related to science practices and the nature of science, and I monitor this development in students from the beginning of the experience. For example, when students make initial observations, I assess if they are ecological in nature. Do they involve the interactions of living organisms with their environment? When students generate questions I assess whether they are descriptive or causal questions, a fundamental consideration I discuss below. What data do students decide to collect and, how do they organize them? Do student conclusions follow logically from their evidence? How well do students field questions from fellow classmates following their group presentation? Essentially, I am interested in how well students ask and answer questions, and then explain their findings.

FUNDAMENTAL CONSIDERATIONS

In this section I briefly describe a number of considerations that I view as fundamental when guiding students in ecological investigations. Naturally, the first is that students have a clear understanding of what ecology is. Ecology is the study of how organisms interact with their environment, including other organisms. It is all about **interactions**, and these interactions can ***biotic*** or ***abiotic***. Students readily grasp the concept of abiotic interactions, volunteering examples such as moisture or light impacting plant growth. They are less clear on biotic examples, saying things like, "a bunny rabbit." I remind them that we are talking about interactions, and point out that an example of a biotic interaction is competition. Then I note that competition can be ***intraspecific*** (within a species) or ***interspecific*** (between different species). Competition among male squirrels for mates is intraspecific competition, and competition between squirrels and chipmunks for acorns is interspecific competition. Other biotic interactions include predation (including herbivory and parasitism), mutualism, and commensalism. I conclude this portion of the discussion with the statement that biotic and abiotic interactions determine the ***distribution*** and ***abundance*** of organisms. Distribution is the geographic area where a species is found. Polar bears are found in the Arctic, for example. I encourage students to pay attention to the "distribution" of various species they encounter. They see ferns growing in forested areas and cattails (*Typha* spp.) growing near ponds and streams (distribution). How many ferns or cattails you find in specific locations (abundance) is determined by any number of factors. More cattails are found closer to the water source, and they dwindle in number farther from the water source. The discussion described in this paragraph takes place before my students' initial focused observation period. My intention is to try get them to make good ecological observations, focusing on interactions of organisms and paying attention to things like intraspecific vs. interspecific competition, and the distribution and abundance of various species.

Another distinction I make sure students understand early in the design of their investigation is the difference between descriptive and causal questions. **Causal** questions (not casual) reflect an interest in the reason something occurs, as in cause and effect. Many causal question begin with "why." *Why does moss grow on the north side of trees?* **Descriptive** questions focus on describing some aspect of nature. *Is moss more abundant on the north* *side of trees?* I ask students which type of question they think is more difficult to answer. Causal questions are usually more difficult to answer with a high degree of certainty because there are potentially multiple factors influencing any particular pattern found in nature. Since the emphasis of my students' investigations is on answering questions with data they collect, I encourage them to ask descriptive questions. A series of descriptive questions can often get at an underlying causal question, however. In an article published in *Science Scope* (Zeeff et al. 2007) on helping students understand the nature of science, my coauthors and I describe an investigation in which students did exactly that. In a forested region on campus they noticed an abundance of oak leaves on the forest floor, but saw mostly maple trees in the canopy above them. They became curious about why this would be and formed the following three questions to investigate:

Are oak trees more abundant than maple trees in the area?

Do oak trees produce more leaves than maple trees?

Do oak leaves decompose more slowly?

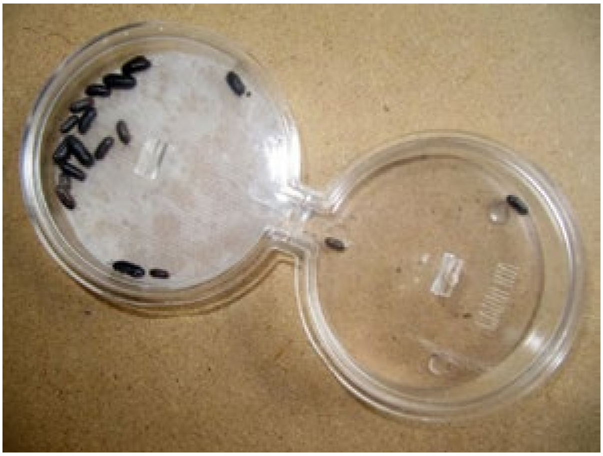
The students counted maple and oak trees in the area and found them to be equally abundant, answering the first question. They sampled the number of leaves on both maple and oak trees and found them also to be equally abundant, answering the second question. To answer the third question, they created decomposition bowls by placing soil, rocks, small branches, and either maple or oak leaves in some medium-sized bowls that they left out in the forest. They checked these periodically to monitor decomposition over several weeks and found that oak leaves do decompose more slowly than maple leaves. Although the questions they asked in their investigation were descriptive, they were able to tentatively answer the causal question as to why they saw more oak leaves on the forest floor than maple leaves.

Another concept that students learn about during the design phase of their investigation is the importance of random sampling and sample size. Imagine some students who were going to sample dandelions on the school grounds by laying down a hula hoop, counting how many plants were contained within, and the multiplying by the number of times the hula hoop would fit across the lawn. They are sampling to estimate the abundance of dandelions. Some students might place the hoop over a large patch of dandelions, while some might place it where there were few to none, probably to be done faster. These are examples of biased sampling. Students conducting investigations in my classes must use **random sampling** to reduce bias. I coauthored an article published in *Science Scope* (Dobson et al. 2017) that details an activity I use with Hershey kisses to have students gain an understanding of this concept. I spread out 100 Hershey kisses on several tables and have students use a plexiglass square that fits 32 times across the table to sample the number of kisses. First students put the square down anywhere they like, usually over the largest groupings of kisses they see. This results in an over estimate of the population of kisses. Then we use an online random number generator to randomly determine where to place the square on the table. This results in a more accurate estimate of the number of kisses. This method of random sampling is being used by the students measuring algae in Figure 2. During the Hershey kisses activity students also see that as **sample size** increases, the estimates become more accurate. Imagine if students were going to sample aphids on a rose bush with 100 leaves. Counting aphids on ten leaves and multiplying by 10 will produce a more accurate estimate than counting aphids on five leaves and multiplying by 20. I encourage students to have as large a sample size as possible, within reason.

CONCLUDING THOUGHTS

Ecological investigations are not restricted to being outside; they can be conducted inside the classroom as well. ***Bottle Biology*** (www.bottlebiology.org) has a number of interesting resources for exploring ecological concepts in the classroom. I am also an advocate for using pillbugs (roly-polies) to have students conduct ecological investigations. I coauthored an article in ***Science and Children*** (Dobson and Postema 2014) that highlights how these easy-to-find invertebrates are an excellent model for students to explore how organisms interact with their physical environment, for example light, temperature, and moisture. Pillbugs are crustaceans, related to organisms like shrimp and crayfish. They possess gill-like structures that require adequate moisture levels to function properly, and this requirement results in particular behaviors and habitats. In the article we describe how to easily raise pillbugs in the classroom in small plastic tubs and how we have had students explore the ecology of pillbugs using choice chambers we purchased from ***Carolina Biological*** (www.carolina.com). Figure 6 shows the preference pillbugs have for a moistened paper towel on one side of a choice chamber. Students could ask if pillbugs prefer a dark or light environment and cover one side of a choice chamber with dark paper or paper towels. Students can put pillbugs in a sandwich-size Tupperware container and float it on top of some ice water. This will result in a behavior called “huddling” as the pillbugs respond to the reduced temperature. Raising your own colonies of pillbugs allows students to make a number of other ecological observations. For example, putting a small frog in with your pillbugs overnight will result in predation. Students will witness this, at least indirectly, as the number of pillbugs declines.

Figure 6. Choice chamber with moist paper towel on the left.



I also wrote several detailed 5E lesson plans that can be used in conjunction with ecological investigations. These are available on my faculty web page, accessible through the Biology Department website at Grand Valley State University (www.gvsu.edu/biology). They cover concepts such as natural selection and adaptation, community structure and succession, biodiversity and conservation, and species diversity and invasive species. The lessons are conducted entirely in the classroom, and any one of them can be used as a primer for students before some kind of outdoor experience. They each can help prepare students to make and ask more ecologically-oriented observations and questions, respectively.

In conclusion, ecological investigations are an excellent way for students to learn science practices and develop an understanding of the nature of science. As educators, we should strive to have students learn science by doing science, and ecological investigations provide an excellent opportunity for that. Through investigations, students discover the power of answering their own questions. They also find that their investigations lead to more questions than they answer. This excitement for science necessarily must come from first-hand experience. Science practices and the nature of science are not best learned through lecture or reading. I do not expect that any one reader will be able to replicate all that I have described in this article. My advice is to incorporate as many elements as you can in guiding your students in ecological investigations. If you made it this far, thank you for reading, and I hope you found this article useful, or at least interesting. If you do intend to guide students in investigations, I encourage you to obtain the other publications and lesson plans referenced in this article, as they contain a fair amount of useful information and activities.

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Why Are We Still Teaching the Scientific Method? A Variety of Reasons

Jim McDonald, Professor of Science Education, Central Michigan University

I am presently spending my sabbatical embedded at an elementary school for a semester. This is a school that I have worked with for 17 years. Supervising student teachers, pre-student teachers, and providing professional development in science have been elements of this relationship.

In preparation for this sabbatical I met with each grade level for 3 hours. I found out about their science teaching and learning resources, the standards that were taught at each grade level, and their familiarity with the Michigan Science Standards. Here is what I found out:

- Many grade levels were not teaching 2 or more standards for their grade;
- Many outdated materials that aligned with the National Science Education Standards but not the Next Generation Science Standards;
- Many teachers using children's literature that still incorporated the scientific method into the storyline;
- An abundance of worksheets for assessment and teaching science at a superficial level; and
- No systematic examination of their science curriculum in 8 to 10 years.

TEACHING THE SCIENTIFIC METHOD

Early in the school year there were a lot of lessons on what is science and what do scientists do. Isolated activities were taught to develop skills like observation, formulating hypotheses, diagrams, labeling, making predictions, and drawing conclusions. One lesson per day taught students the steps in the scientific method. It is typical for science curricular resources to devote the first chapter to the scientific method or the scientific process. Why do we do this? There are a few reasons.

There are three excellent sources to see why we have taught the scientific method in American schools for so long. The first source is the National Research Council Framework for K-12 Science Education. I go back to this source periodically to make that my own science teaching is grounded in current practices.

The Framework (2012) states:

> The notion that there is a single scientific method of observation, hypothesis, deduction, and conclusion—a myth perpetuated to this day by many textbooks—is fundamentally wrong. Scientists do use deductive reasoning, but they also search for patterns, classify different objects, make generalizations from repeated

> observations, and engage in a process of making inferences as to what might be the best explanation. Thus, the picture of scientific reasoning is richer, more complex, and more diverse than the image of a linear and unitary scientific method would suggest (p.78).

In many classrooms at the school where I was embedded skills were being taught that included observation, diagramming, labeling, and stating hypotheses. The sources for this series of activities in classrooms came from Teachers Pay Teachers, outdated kits and textbooks, or something that the teacher had used for many years.

The second source that should inform your teaching, or not teaching, the scientific method is How We Teach Science, What Has Changed, and Why That Matters by John Rudolph. Rudolph (2019) relates that in the 1920s and 1930s it was thought "that public training in the scientific method was essential to human progress" (p.123). Karl Pearson in his work The Grammar of Science (1892) said, "The importance of a just appreciation of scientific method is so great that I think the state may be reasonably called upon to place instruction in pure science within the reach of all its citizens." It went so far as to use the scientific method in music and social science education as well.

Educators and some scientists objected saying it did not apply to all situations. Percy Bridgeman represented this group when he said

It seems to me that there is a great deal of ballyhoo about scientific method. There were no steps in his mind. Scientific method is what working scientists do, not what other people say about it. For a scientist the essence of the situation is that he is not consciously following any prescribed course of action. If there was a scientific method to be had it is nothing more than doing one's damnedest with one's mind, no holds barred which is about as far from a method as one can get. (Percy Bridgeman as quoted in Rudolph, 2019, p. 130)

The third source is STEM Teaching Tools from the University of Washington (stemteachingtools.org). Two key points made in Brief 32 (2015):

- The "scientific method" makes science into a series of rigid steps— and can lead students to disengage. In contrast, practices highlight how science is a highly social, creative, and iterative problem-solving process involving a variety of different kinds of intellectual work.
- Engaging students in the science and engineering practices can support important cognitive, social, and cultural learning processes. The practices also provide opportunities to draw upon the many ways that young people and communities make sense of the natural world.

TRADE BOOKS

Children's literature can give elementary students both a good idea and a bad/misconceived idea about how science in conducted. An example of each is presented in the following two books.

CHARLOTTE THE SCIENTIST IS SQUISHED

This book by author Camille Andros and illustrated by Brianne Farley is about a rabbit scientist named Charlotte who uses the scientific methods to do experiments to solve her problems.

Here problem is that she needs more room. She has so many brothers and sisters that she is too squished to work on her experiments. Can she use science to solve her problems?

The story is a cute one but very much matches the view discussed in Rudolph that the scientific methods can be used to solved any of your problems, as long as you follow the steps. This is misleading for elementary students and completely ignores that science should be taught for understanding. The five steps of the scientific method used in the book are ask a question, form a hypothesis, test the hypothesis—experiment, make and record observations, and form a conclusion. We use the NGSS science and engineering practices instead because students learn how to ask their own questions (often more than one), plan and carry out investigation, use evidence to explain their understanding (engage in argument with evidence), and communicate findings. Since the scientific method follows a linear process in a one size fits all manner, students will get the wrong idea about the process of science. If we teach for engagement, we should use the science and engineering practices.

ADA TWIST SCIENTIST

Andrea Beatty is one of my favorite authors. She has written Iggy Peck Architect, Rosie Revere Engineer, and Ada Twist Scientist. These are three characters that are in the same second grade class at Blue River Creek Elementary School. Ada Twist is a positive way to portray how science teaching and learning happen.

Ada's head is full of questions and her parents tell her that "you will figure it out. The questions are posed as she investigates why it is called a grandfather clock, what is causing the terrible smell around her house, and the sounds that mockingbirds sing. When her parents get frustrated, they send her to the thinking chair but soon witness her questioning process as she maps out her thoughts on the hallway wall. What should they do with this curious kid? You'll figure it out becomes "we'll figure it out". It has turned from an individual process into a collective family and teacher/student process.

To me this models how we should allow students to make mistakes and learn from them. Call it a growth mindset that lets students add to their knowledge when they encounter new things. Learning through personal experience enhances understanding. I am a constructivist at heart, and I believe that students need to encounter knowledge first-hand in whatever process leads them to understanding. Science can be muddy and messy, and it takes time.

In Seeing Students Learn Science (2017) says that students should be allowed to learn science gradually. "When we see the purpose of science education as helping students learn to reason, ask questions, and test their ideas the way that scientists and engineers do, it's a reminder that learning develops gradually over time" (p. 11).

Contrast this with the scientific method that turns learning into memorization, a static and stale process, and does not work toward understanding. The scientific method implies that if you simply follow the process, you will arrive at the answer. This is not true when it happens quickly and then we move on to the next chapter in the book or next activity in the curriculum.

A book like Ada Twist looks at her gradual learning process and that she perseveres in her curiosity to find answers to her own questions. This is the deliberative learning process that elementary students need to follow, with planning by the teacher, to see how science is done in the real world and in a relevant manner.

CONCLUSION

Be discerning when it comes to choosing materials to teach science. Ask yourself some important questions when planning for science instruction:

- Does the book you are reading to your class add value to the unit of instruction?
- Are you doing an interactive read aloud with your students when using children's literature?
- How engaging is your science lesson and plan for instruction?
- Are your using up to date materials when teaching science?
- Is your science instruction following a step by method with a predetermined outcome? Do students have to get the right answer to get a good evaluation on their assessments? Or do students have to explain their thinking to how proficiency and understanding?

That school that I was working with, what progress are they making? Teachers are engaging their students with natural phenomena. Take the following examples:

- A first-grade learning objects in the sky, goes out several times during the day to see how shadows move even when standing on the same spot. The students are so engaged that they want to work in partners to trace everyone's shadows.
- A fourth grade studying moon phases does moon phase modeling, sends home a natural phenomenon project so that students can do observations with their parents.
- A third-grade class uses an interactive read aloud using weather books, goes outside to measure weather and will do it long enough to get into investigations about climate.
- A second-grade class examining science and what scientists do, is learning how to come up with their own questions and conduct their own investigation with the life cycle of the butterfly.

All of this is happening gradually with five to six science standards a year, integrating science with writing, reading, math, and social studies. This allows for deeper learning while engaging students with relevant information as they develop their own understanding of crucial science concepts in a 3D manner.

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“Helium Shortage May Have Grounded the Weather Balloon Project, But it Wasn’t the End of the Lesson”

By Jason Scott, Middle School Science Teacher, Petoskey St. Francis Xavier School

Sometimes even the best made plans do not succeed. We are all familiar with this possibility and you may have experienced it yourself from time to time. In spite of your best made lesson plan, the plan where you believe you’ve crossed all of your ‘T’s’, and dotted your ‘I’s’, there was one variable you could never have accounted for that puts all of your hard work and the lesson itself in peril. This is where I found myself last May in the 7th grade weather balloon project, but in teaching, as in life, we need to find the opportunities opening around us when the one we worked for closes abruptly in our face.

The idea to launch a weather balloon with a payload of tiny computers taking readings on global position, altitude, and temperature came from a science teacher conference I attended in the Fall of 2014. I viewed the homemade videos his students made and samples of the data they took in their launches and I was hooked. The GoPro video and images taken at 80,000 feet were some of the coolest things I had ever seen, and this was something I needed to do with my middle school students.

Fate favors the bold, but it wasn’t until the spring of 2018 that I found myself in a position to be able to do the weather balloon project with my students. I teamed up with a weatherman from a local TV news broadcast, which gave me an advantage in wind forecasting. Tom O’Hare from Channels 9 and 10 News loved the idea and visited my classroom to talk to the students about being a meteorologist. The students then went to the Channels 9 and 10 News Studio, took a tour, did mock forecasts next to the green screen, and watched a news broadcast being aired live from the news studio. After our units on weather, the atmosphere, and the hydrosphere, we were ready to pull it all together with our first ever weather balloon launch.

We had mixed success. It took two attempts to get the computer payload airborne. The weather balloon broke the string that came with the weather balloon kit on our first try, and on our second try, the student responsible for inserting the mini SD card into the computer, put it in upside down. We did however, get some great video of the flight, and my next class vowed to achieve success no matter what.

The 7th graders of the Spring of 2019 had learned from the previous class’ mistakes. Tom O’Hare was still willing to do the launch with us. Furthermore, I had secured a grant to purchase a new balloon and more supplies for the launch, including a new GoPro camera. Everything was coming together when that one variable I could never have predicted ensured the weather balloon project would not get off the ground…literally.

The United States had a nationwide helium shortage in 2019. The salesman who helped me secure the helium the year before interrupted me asking for more with, "Never gonna happen!" Thinking they had run out and were waiting for more to come in a shipment, I tried to postpone my purchase for a later date and received the same response, "never gonna happen then either. We are in a helium shortage and we have no helium available for the next few months at the soonest. Sorry."

That was it, the weather balloon project was officially called off for 2019. The students and I were devastated, and adding irony to the sad announcement, on my way home that day while listening to the news, there was a story about the shortage of helium in our country. Channels 9 and 10 News also did a story on it that evening, and it was while watching it that the idea for a new lesson came to me. My students would research and attempt to solve the helium shortage.

The first part of the lesson consisted of showing the students some brief clips about the Hindenburg Disaster in which the Hindenburg Blimp caught fire because it used hydrogen gas instead of helium. The reason, only the United States had enough helium manufactured to raise a blimp, and Germany, not wanting to seem inferior to anyone in the 1930's chose to use the one gas they had plenty of-hydrogen. So, if the United States was and still is the largest producer of helium gas, why do we have a shortage? The students composed a list of essential questions that needed to be answered first before understanding our current helium circumstance.

The list of essential questions, after some prodding, started to materialize. We went from, "what is helium," and "why is it the 2nd most abundant element in the universe," to more critical questions like, "where do we find helium on our planet," and "how do we get helium?" I then had students break into teams, choose two questions from the list, and had them research the answers online. After spending a couple of class periods locating answers, the students came up with some very good information to help us address the problem of a helium shortage.

The small teams of students had to present their findings to their peers who took notes on the answers, then each group had to take the information and summarize the problem of the helium shortage in 1-2 paragraphs. The next phase of the lesson was to determine if helium was a renewable or non-renewable resource, and if non-renewable, what are actions we can take to solve the helium shortage. The students correctly concluded helium was a nonrenewable resource with only a limited number of known reserves making the helium shortage a potentially long term problem. The final phases of this lesson were the hardest for students- develop a solution to the problem and relate the helium shortage to other issues centered on the depleting supplies of other non-renewable resources.

In the end, the students did not get to launch a weather balloon into the stratosphere, and after checking with my industrial gas supplier, it doesn't look promising for another launch in the near future. However, the lesson that resulted for this unfortunate circumstance was a very valuable experience for them. In the end, they realized that helium, like other non-renewable natural resources needs to be conserved to ensure a long time supply, which requires us to make difficult decisions that prioritize what we use helium for. I like to think that for them, as it was for me when I attended graduation open houses at the end of the school year and saw helium inflated balloons used as decoration, there was the itching question, "Are we using our natural resources wisely?"

NGSS LESSON PLANNING TEMPLATE

Grade/ Grade Band: 7	Topic: Helium Shortage

Brief Lesson Description: Students will discover how we could have a shortage of the second most abundant element in the universe.

Performance Expectation(s): Students will discover different methods for helium creation in the universe and on Earth.

Students will understand why we have a shortage of the second most abundant element in the universe on Earth.

Specific Learning Outcomes: Students will summarize how helium is created naturally in the universe, how we harvest it on Earth, and why we have a shortage of helium currently in our country.

Students will develop a solution to either increase our production of helium or through conservation, limit our uses of it.

Students will relate helium to other natural resources that we use and the need for conservation if it is not a renewable resource.

Narrative / Background Information

Prior Student Knowledge: Students should know that Helium is an element, it is the 2nd most abundant element in our universe, and it is the 2nd smallest atomic particle making it less dense than other gases in our atmosphere, which allows objects filled with it to seemingly float.

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Asking Questions and Defining Problems Constructing Explanations and Designing solutions	**PS1.A: Structure and Properties of Matter** -Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it **ESS3 Earth and Human Activity** **ESS3.A: Natural Resources** -Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.	**Cause and Effect**- Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering. **Structure and Function**-The way an object is shaped or structured determines many of its properties and functions.

Possible Preconceptions/Misconceptions:

Helium is created naturally and is the 2nd most abundant element in the universe. Most gifts stores and party suppliers sell helium in tanks for balloons. This does not necessarily mean though that it is abundant throughout our planet and atmosphere which is a common misconception.

Helium is not an easy element to harvest from chemical processes in mass quantities regardless of its availability in the past in party supply stores and other retailers.

LESSON PLAN – 5-E Model
ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions: Announce to the class that we have to cancel our weather balloon launch due to a shortage of available helium in our country currently which has caused restrictions in the amount, what it can be used for, and to whom it can be sold to. Tell students they need to discover what caused the shortage of helium and create solutions to prevent helium shortages in the future. Ask students to create a list of essential questions that would help understand how we now have a shortage of helium.
EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions: Divide students up into teams of three or four. Assign each group 1-2 essential questions to research on the internet and report out on to the other groups.
EXPLAIN: Concepts Explained and Vocabulary Defined: While each group reports their researched answers, other groups are to take notes on the answers to the essential questions they did not research themselves. Explain to students that any time we have a shortage of a resource, it is either caused by a severe limitation on how much of the resource is available, the amount of time it takes for the resource to be produced naturally, or an inequality between the rate the resource is used versus how much of it is available. Student teams are to write a 1-2 paragraph explanation on why we currently have a helium shortage in our country as a result of one or more of these three causes. **Vocabulary:** Nuclear Reaction. Fission, Fusion, Radioactive Decay, Natural Resource, Consumption, Production, Conservation, Supply and Demand
ELABORATE: Applications and Extensions: Explain to students that with every natural resource shortage we can either increase production by increasing mining, farming, or collection of the resource, or reduce our use of it through conservation practices that prioritize who and how we use the resource. Keeping the same research groups intact, have each team brainstorm solutions to solve the helium shortage in the United States. Students then need to choose one of their solutions and research how they could implement it.
EVALUATE: Summative Assessment: Student teams are to write a 1-2 paragraph explanation on why we currently have a helium shortage in our country and then another 1-2 paragraphs describing their solution to the helium shortage crisis in the United States.
Elaborate Further / Reflect: Enrichment: Helium is just one natural resource that we have had to monitor and place restrictions on due to a lack of supply. Teams will choose another natural resource with a limited supply and research answers to the following questions: 1. Where in the world or country is the limit in supply of this resource having the greatest impact? 2. Is this resource renewable? 3. If yes, how long does it take to renew this resource? If no, when is this resource projected to run out based on current supplies and demands? 4. What are some actions we can take now to either increase our supply or conserve our use to ensure there is not a shortage of this resource?

Modeling and Mathematics: How to Make Motion on a Motionless Medium

By Andrew T. Frisch, Farwell High School

Modeling and mathematics are both load-stones of the Next Generation Science Standards and S.T.E.M education. However, achieving these two tasks can prove to be challenging. There are modeling kits, but they tend to be expensive and subject matter specific. Computer animations are available, but they are not student-created and lack human-to-human communication.

Plain paper and a pencil (*Opportunity* and *Respect* in my classroom) are all that will be needed to complete these modeling activities and are easily modifiable for many science disciplines.

"Action lines!" Comic books have used them for years to show power, strength and speed. Action lines are a simple, versatile, and highly effective technique to model movement and/or action. They allow models to have variation in frequency, speed, intensity, along with others.

MODELING LESSON PLAN: THERMAL ENERGY. HEATING UP AND COOLING DOWN

Background:

In many ninth grade Physical Science classes, the five forms of energy (PS3.A) and energy transfers (PS3.B) are covered as Disciplinary Core Idea.

What are atoms doing differently within a *hot rock, room-temperature rock, and a cold rock?*

What happens to the atomic movement and thermal energy, both kinetic to potential, as the hot rock cools down and the cold rock heats up? What happens to the room-temperature rock?

Materials:

- Three nearly same size and shaped rocks, about the size of a soft ball.
- Hot Plate with a 3-quart pot full of water.
- Cooler or tray full of ice.

Set up:

- Use a hot plate to heat water and one rock: Hot Rock
- Use the tray of ice to keep the pre-frozen rock cold: Cold Rock
- Leave one rock sitting in the room: Room-temperature Rock

Begin class by placing all three, dried rocks on to the countertop next to each other. Have the students come up and touch each rock. Allow them to have a tactical experience of various thermal energies.

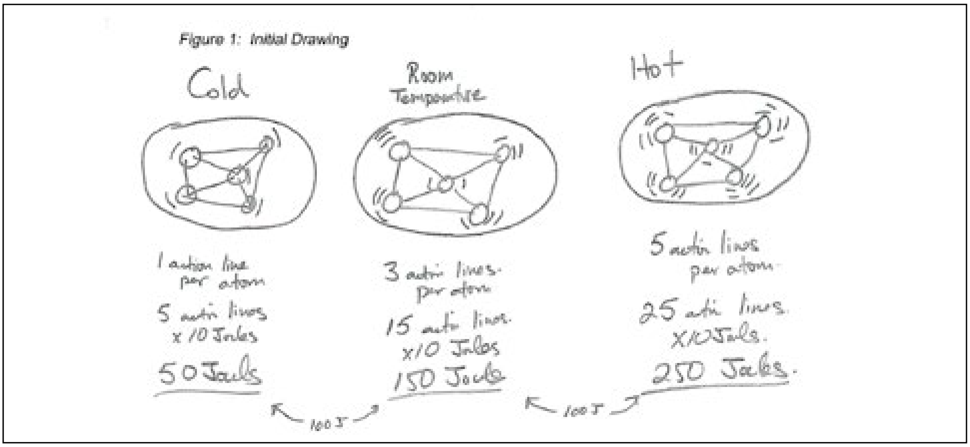
As the students return their seats, have them communicate with each other about what they felt. Allow them time to share their ideas about each rock, lead the discussion to the driving question, "What will happen to the hot, cold, and room-temp rocks' heat energy as class period goes on?"

The cold rock will get warmer; and the hot rock will get cooler.

Modeling and Mathematics:

Create the following models together using paper and pencil. *(See Figure 1).*

- Draw three large circles to represent the cold, room temperature, and hot rocks.
- Draw five small circles within each rock. Each circle represents one kilogram. (This is not accurate, but it provides the connection between mass and its unit.)
- Draw lines between the atoms. All atoms must be connected to make it a solid. (Inquire how the models would be different as a liquid or gas?)
- Draw one action line (I use parenthesis as the symbol) around each cold atom, for a total of 5 action lines.
- Draw three action lines (parenthesis symbols) around each room temp atom, for a total of 15 action lines.
- Draw five action lines (parenthesis symbols) around each hot atom, for a total of 25 action lines



Action lines ") or))" represent various levels of atomic vibration; more action lines mean more energy, fewer lines mean less energy. The law of conservation of energy requires that energy is not to be created or destroyed. Where do the action lines or energy come from and where do they go?

In this model, the atomic structure is not as important at the atomic vibrations. In addition, depending on the level of your students' mathematics the exactness of the values is less important than the conceptual thinking and patterns found within the phenomena. For example, in this model there are only five atoms randomly bonded together and each action line represents 10 Joules. This is not exactly correct, but it does provide the conceptualization of adding or removing a specific number of units of energy every time and that there is a specific number of atoms. Later these concepts would be modeled as *specific heat* and *mass.*

- Calculate the thermal energy of each rock.

  Energy (number of action lines **times** 10) per atom times the number of atoms **equals** the total energy.

Specific Heat X Mass = Thermal Energy

- Redraw the hot and cold rocks, modeling how their thermal energies will spontaneously transfer from the hotter substance to the colder as class time progresses. The models must provide an explanation of where the energy to make or remove action lines comes from and goes. (*See Figures 2 and 3*).
- In the redraw, add arrows "➔" to represent kinetic energy being added or removed from the environment. Each arrow will also represent 10 joules.
- In the *Cold Rock* model, ten arrows (100 Joules) must be drawn going into the rock, kinetic energy, to equal the ten action lines (100 Joules; two per atom) that have been added to the rock, potential energy.
- In the *Hot Rock* model, ten arrows (100 Joules) must be drawn going out of the rock, kinetic energy, to equal the ten action lines (100 Joules; two per atom) that have been removed from the rock, potential energy.

Figure 2: Action of Atoms in the Cold Rock

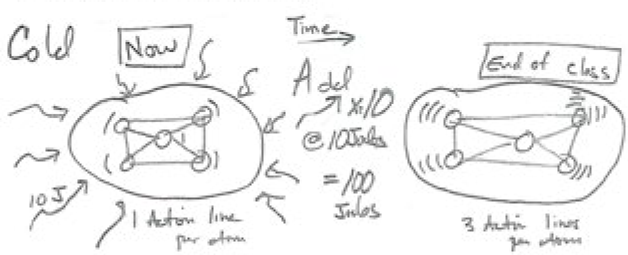


Figure 3: Action of Atoms in the Hot Rock

Extensions:

Additional examples should be redrawn to verify modeling and mathematic conceptualization.

Where did the hot rock get its energy from to become hot? How was the cold rock cooled; what about previous thermal energies?

How would making the rocks smaller change the model? Would they release as much energy?

How would making the rock hotter change the model? Would it require more energy to get hotter?

What if it was a different material? How would that change the action lines?

Use timers and thermometer to measure rate and temperature changes.

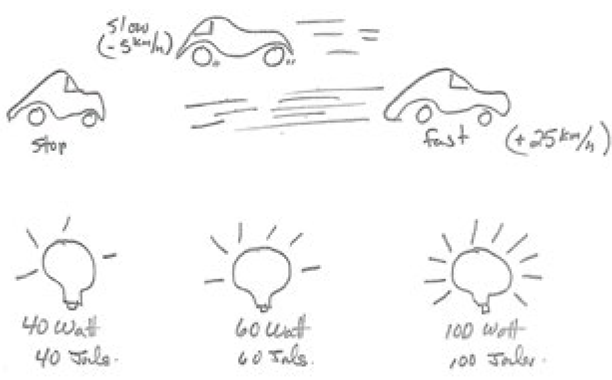
My favorite-Show a video clip of "a lava burp" at the exact moment when the lava boils and splashes like boiling water. Then have the students draw a model based on the one we created in class that would illustrate the "lava burp."

Other Applications:

There are other opportunities to use actions lines as a modeling tool. *(See Figure 4)*. As in motion, speed can easily be modeled as horizontal lines drawn trailing the moving object, variations in length and number could represent changes in energy and speed. Light intensity is another example of using action lines as a modeling tool in physics; it is called a "star burst". The number of lines in the star represents its brightness. Brightness is measured in lumens.

When we are modeling, we have to put our comic book artist hat on. Think how great comic books show action and strength. These are simple but effective techniques to show movement and intensity. Talk to our art teacher friends for more ideas. Use your cross-curriculum connections to help students better understand energy and make motion on a motionless medium.

Figure 4: Other Applications



Technology and Data: Use Simple Tools to Calculate Terminal Velocity

By Andrew T. Frisch, Farwell High School

The Engineering Practices within the Next Generation Science Standards requires the use of technology to collect data that can then be mathematically evaluated to recognize patterns to make predictions. All that being said, we, science teachers, need to get tools into our students' hands, so they can use them to make measurements. Then write those measurements down as data to see what can be figured out.

Technology is the use of tools. Not all tools need to be electronic, some of the best technology is simple, hand-held, and available. Paper, pencils, rulers or meter sticks, timers, electronic scale, and calculator can go a long way. These tools allow students to collect real data, in real time that can used as the basis of many mathematical concepts.

This is a description of a lesson plan that was developed in the RET program within the College of the Engineering and Technology at Central Michigan University. The materials are readily available and there are extensions that could be applied to make the mathematical relationships and computations quite advanced.

continued on page 40

LESSON PLAN: USE COFFEE FILTERS TO DETERMINE TERMINAL VELOCITY.

Background:

In Physical Science and Physics classes, the five forms of energy (PS3.A) and energy transfers (PS3.B) are covered as Disciplinary Core Idea.

As an object fall towards the earth, it reaches terminal velocity when the force of air resistance is equal to its weight. The terminal velocity varies based on the surface area and weight of the falling object.

Falling times of coffee filters at various heights will be measured to ensure they are falling at a terminal velocity, then the terminal velocity will be calculated, to determine the relationship between mass and its terminal velocity. With possible extensions into other falling objects and the possibility the calculation of the coefficient of friction.

Materials:

Use the "Raining Coffee Filters" lab sheet to provide structure to the lesson.

Extensions:

Use Styrofoam spheres of various diameters to repeat the lab sheets, this time is will be called, "Raining Styrofoam Balls". The data should be used to find the relationship between terminal velocity and radius. (Hint: terminal velocity is related to surface area, which is radius squared, while weight is related to volume, which is radius cubed.)

Use the coffee filters and challenge the students to make the coffee filter fall as slow as possible and hand within a given circular target place on the floor. Students can manipulate the shape of the filter and the height of the fall, but they only get one test trail and it must hit the target.

Raining Coffee Filters

***Name*__________________**

Purpose:

To describe (graph and calculate) the motion of falling object.

Materials:

Meter stick, five (5) coffee filters, tape, and stop watch.

Procedure:

Work with a partner; one will be "the dropper" and the other "the timer".

Using the meter stick, measure and mark with the tape heights of 100 cm, 150 cm, 200 cm, 250 cm.

Begin with one coffee filter. Drop and record the time it takes for one coffee filter to fall 100 cm. (This is called hang time.)

Drop the same coffee filter two more times for a total of three times and calculate the average time for one coffee filter at 100 cm. Use the average time as its "hang time".

Repeat this one coffee filter drop at the other heights of 150 cm, 200 cm, and 250 cm. Again do all heights three times, calculate the average, and use the average as the hang time.

Once all of the data has been collected and recorded by dropping one coffee filter, repeat all of the drops from all of the marked heights this time using three (3) coffee filters.

Once all of the data has been collected and recorded by dropping three coffee filter, repeat all of the drops from all of the marked heights this time using five (5) coffee filters.

After all the data has been collected and calculated, create three separate graphs. Title them: *Hang Time of One Coffee Filter at Various Heights, Hang Time of Three Coffee Filter at Various Heights, and Hang Time of Five Coffee Filter at Various Heights.*

Set up each graph with the appropriate X and Y axis, label them and determine appropriate intervals.

Complete the questions.

Data:

One coffee filter

	100 cm	150 cm	200 cm	250 cm
Hang time 1				
Hang time 2				
Hang time 3				
Average				

Three coffee filters

	100 cm	150 cm	200 cm	250 cm
Hang time 1				
Hang time 2				
Hang time 3				
Average				

Five coffee filters

	100 cm	150 cm	200 cm	250 cm
Hang time 1				
Hang time 2				
Hang time 3				
Average				

Data Analysis:

Create a graph for each data set with the distance of each fall as the independent variable and the hang time is the dependent variable. Draw the line of best fit.

Questions:

1. Are the graphs linear or non-liner?

2. Calculate the slope of each graph.

   a. Slope of one filters graph.

   b. Slope of three filters graph.

   c. Slope of five filters graph.

3. What does the slope represent?

4. Do the filters continue to accelerate throughout the fall or do they reach terminal velocity? Explain your answer.

5. What are the forces acting on the coffee filters?

6. Use the forces acting on the filters to explain the motion of the coffee filters as they fall. (Use the answers given in question 5 to explain question 4.)

Invasion Meltdown: a lesson meltdown saved by invasion-wise elementary students

By Meredith A. Zettlemoyer (Kellogg Biological Station; zettlem2@msu.edu)

INTRODUCTION

Invasive species represent a serious threat to the health of our native ecosystems and our daily lives. These non-native plants and animals disrupt food production, agriculture, natural resources, waterways, recreation...the list is endless, and the damage caused can cost billions in time, money, and resources (Padilla and Williams 2004, Pimentel 2009). The impacts reach national scales, but local consequences are already recognized by land managers and educators (Hakam 2016). It is the next generation that will have to take care of our damaged ecosystems, so their decisions, actions, and knowledge will play into the establishment and prevention of invasive species' spread in the future.

Despite this, many students can neither name an invasive plant or animal in their home state nor the extent of the problem (Hakam 2016). There are hundreds of research articles floating around in the nether of scientific literature, but how can we translate this into secondary school classrooms? McGuire's (2015) identity-based environmental education model addresses this: we can help students generate environmental identity, and hopefully stewardship, through public education and outreach programs.

The K-12 Partnership at the W.K. Kellogg Biological Station hosts three annual professional development workshops for K-12 STEM educators from across Michigan, where researchers develop classroom activities based on their own work and hot topics in ecology and environmental science. In the evaluation form from one of these workshops, invasive species came up as a suggestion for a future session theme. During the following workshop, I took on an invasive species session, which played out in a tale of the folly of candy, exploding pom-poms, and the power of the Bee Gees' 'Stayin' Alive'.

Our first run at an invasion lesson: chaos ensued

In this lesson, we decided to teach about the role invasive species play in native ecosystems, focusing on Michigan's invasive species, and developed a game where students, playing as invasive and native insects, would compete for resources. After learning about basic invasion biology and seeing some "Most Wanted" profiles of our most prolific local invaders, students would be introduced to some of the adaptations and effects of invasive species, including resource limitation and biodiversity decline. Our goal: drive every single native species extinct.

The first time I presented this lesson was to mostly middle-and high-school science teachers. The teachers split into groups: one person at each table was the emerald ash borer, a voracious wood-eating insect that has decimated ash trees across North

America. Everyone else was assigned a native bug of a particular color. They had to compete for food resources in their habitat: M&Ms. We set some basic rules of invasive species' biology: they are more competitive (could use two hands to collect more 'food resources' at a time) and are generalist feeders (can collect any color M&M). Meanwhile, the native species specialized on a particular color M&M and could only collect one at a time. We played in rounds, so everyone had 20 seconds to collect the food they needed to survive. Eventually, your species wouldn't have any more food available to it and would be "extinct". Once that happened, you transformed into an emerald ash borer (think of this as rapidly reproducing invasive populations) and played as one of the invaders. After a few rounds, we threw in some jellybeans to represent polluted food resources: native species couldn't recognize the threat, so if they accidentally collected too many toxic resources, they died. We set everything up with our one goal in mind.

What a disaster.

> Error #1: candy. We had candy going into people's mouths, onto the floor, halfway across the room. I was yelling out "Time's up!" after every round over the resulting hyperactivity.
>
> Error #2: letting people choose whatever native bug most appealed to them. We had so many cute green caterpillars, all the green M&Ms vanished and the caterpillars died within minutes. Meanwhile, our native brown insects survived just fine.
>
> Error #3: not having a minimum amount of food resources needed to survive. Some native insects elected to starve themselves instead of attempt to collect polluted jellybeans. A wise strategy? Yes. A biological suicide mission in a real ecosystem? Definitely.

Needless to say, the feedback from this activity was mixed:

- "Fun and locally relevant." Check - studies have shown that an understanding of invasive species in people's own communities are more likely to promote engagement (Hashitomo-Martell and Mcneill 2012).
- "Neat game… not with M&Ms though." Our opinion too!
- And my personal favorite: a "hot mess."

Take two: the knowledge of some incredible fourth-graders

A few months later we had the opportunity to present at Women in Engineering's Girls' STEM Day at Michigan State University. We needed a quick lesson, doable in 20-minute shifts. The most rapid-fire lesson plan we had available was the invasion game. But there was no way we could go into a classroom full of 1st-4th grade girls with the chaos that had ensued last time.

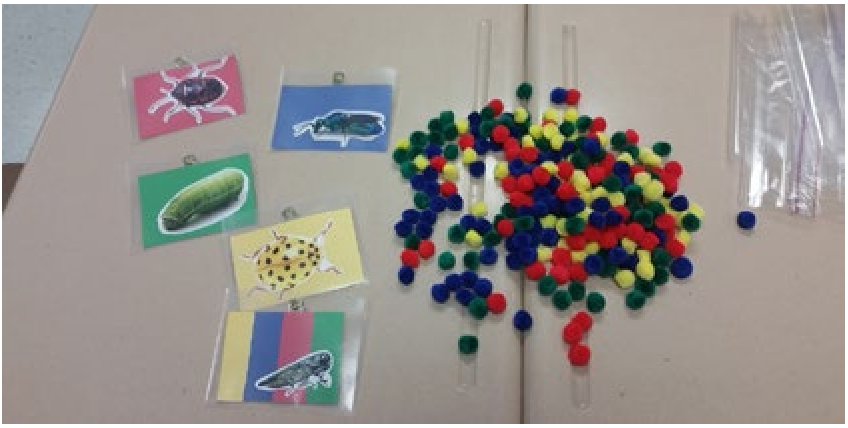
We ended up developing the game for groups of 5 students: 1 emerald ash borer and 4 native species of red, yellow, green, and blue. We bought pom-poms in matching colors and made player cards for each student. In order to make it through a round, you had to collect at least 3 pom-poms: if you were an insect and you were out of food, wouldn't you at least try to eat something else? Finally, to top it off (and entertain the parents in the back of the classroom) in a nod to musical chairs, we blasted "Stayin' Alive" through each 20-second round so that the girls would freeze as soon as the music stopped. Anyone who was out of food raised their hands so that we could tally who'd died and needed to switch to the ever-growing population of emerald ash borers.

This was without a doubt one of the most successful K-12 lessons I have participated in. The girls were collecting as quickly as possible, scavenging any pom-poms that fell to the floor in an attempt to survive, and carefully tracked their food intake as food got scarcer and scarcer.

We then tossed in some glittery pom-poms as a poisonous little twist. If you accidentally collect this food, you have to keep it: this was the new rule. If you're out of your healthy food source, what are you going to eat? Different strategies popped up: some collected much slower, avoiding the poison but sometimes not collecting their minimum food requirement as time wore on. Some girls took the dangerous approach and even closed their eyes ("Would they know it was poison?") and took their chances. By the end of a few rounds, when we asked who was still alive, not a hand raised. When we asked who was playing as an emerald ash borer, two dozen hands with emerald ash borer cards popped up - they'd taken over!

The most rewarding part of this was the follow-up discussion. We didn't have time to do walk through a complete lesson plan, but we wanted the girls to understand why invasive species are so damaging and link this to species in their own neighborhoods. We started off by having the students name as many invasive species as they could, not expecting more than a vague "ivy" or "snails." Instead, we got stink-bugs, zebra mussels, Asian carp, emerald ash borers, spotted knapweed, purple loosestrife...all invasive species that have been particularly damaging to Michigan's native habitats. The highlight was when one girl, in responding to my questions about what an invasive species is and what adaptations make them competitive, proceeded to give me a more thorough answer than some undergraduates would give: "A species that is foreign to an environment and has damaging effects, that can eat anything and grow quickly and has lots of babies." She even threw in the enemy-release hypothesis, an idea in invasion biology that predicts that invaders spread because they no longer have natural predators or enemies to keep their populations in check, and allelopathy, a plant's ability to release chemicals that inhibit any nearby germination. These students engaged with a local environmental issue, and actively acquired information through both past knowledge and the game.

M. Zettlemoyer adding toxic plants to the insects' food supplies at the Girls' STEM Day (2018 17 November).



Sample pieces for the Invasion Meltdown game, including food resources and playing cards. Each native insect feeds on only one color pom-pom, while the invasive emerald ash borer can feed on yellow, blue, red, or green pom-poms.

CONCLUSIONS

When every single student in the room raised an emerald ash borer at the end of the game, it clicked: invasive species cause the extinction of our native species. We were able to discuss human-caused changes to the environment when they recognized that pollution caused extinction to happen even more rapidly. This lesson addressed the NGSS standards relating to environmental change (3-LS4-1, LS2.C), cause and effect (3-LS4-2-3), and constructing explanations (3-LS4-2-3). Beyond that, it demonstrated the mechanisms by which invasive species are so competitive and problematic and how humans compound that threat, and engaged the students in how their own homes might be impacted. This last lesson, hopefully, will be the link to place that helps them grow into the environmental stewards of tomorrow.

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SUPPLEMENTARY MATERIALS

The resources for the "Invasion Meltdown!" lesson (lesson plan, PowerPoint, and insects for the game) can be found in the folder at: https://drive.google.com/open?id=1IBJ0ro1wHxaM5MqLI7I5_ou-MdFcy3Ut

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