METACOGNITION AND THE NEXT GENERATION SCIENCE STANDARDS

by

Bobbi Lynn Monroe

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DEDICATION

I would like to thank my own former science teacher and best friend, Mr. John R. Allen for inspiring and cultivating my love of science in my past as a student, being a treasured and stalwart confidant in my present, and for the continued guidance and camaraderie far into my future.

I would also like to thank my delightful, inquisitive, and supportive daughter, Annika Allison. She has been patient, encouraging, and understanding through the long hours, days, weeks, months, and years this labor of love has taken.

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ABSTRACT

Middle school seventh grade science students need to improve retention, understanding, and transfer of the science and engineering practices within the Next Generation Science Standards. Metacognitive strategies were introduced to the students' lessons at the beginning and end of each meeting time to reflect on the practice or practices used during the lesson, lab, or activity. Quarter grades from assessments covering the practices were used before and after the intervention to measure learning gains. Student surveys were also administered to determine understanding, enjoyment, and engagement of the technique. Interpretation and conclusion are to be discussed after completion of this action research.

INTRODUCTION AND BACKGROUND

For the past four years I have been investigating and implementing the Next Generation Science Standards into my teaching practices of middle school science students. I have been to conferences, worked with consultants, and served on a curriculum steering committee to better understand the NGSS and the process of instruction and assessment using the three-dimensions. While it has been a time-consuming endeavor, it has been something I feel is valuable and worthy.

Casual observation of my students' interest and understanding of concepts through the practices led me to choose this path of research for my classroom research project. I wanted to see if those observations were indeed factual and measureable. I have honed my instructional and assessment practices to best implement the NGSS and will be using an intervention to measure the use of the Science and Engineering Practices within my classroom.

My research is focused on my seventh-grade students' use of metacognitive strategies to enhance the transfer of learning and understanding of the Science and Engineering Practices within the Next Generation Science Standards.

Demographics

The school where I am currently teaching is located in Atherton in California and is called Menlo School. Opening in 1915, the school is private and secular with a long tradition and history in the Bay Area.

We are a 6-12 school with a total student population of 795 students. Almost all students have a very high socioeconomic status. However, the school seeks to attract talented students from a variety of socioeconomic backgrounds and awarded $6.1 million in fund-raised aid to 22% of the student population for the 2017-2018 school year. Considering diversity, 50% of the students identify as non-white.

The students, for the most part, are very academic and curious. While they enjoy the process of science, they usually will want to uncover the answer instead of uncovering more questions. They show a high ability to regurgitate information and are usually overly concerned with grades more than understanding. The introduction of the science and engineering practices, and the grading of those practices, was often met with frustration and resentment because the students couldn't simply memorize concepts and definitions. They needed to apply their understanding in new situations using those practices. This was something that was new to them and they were at a loss with how to get better on their own. I thought that more understanding of the practices and the nature of science through metacognition would allow students to feel more confident in their abilities and their understanding would deepen.

Observations of my students led me to develop the following focus question: How does the integration of metacognitive strategies impact student understanding and transfer of the NGSS Science and Engineering Practices?

CONCEPTUAL FRAMEWORK

A Nation at Risk has echoed the "new basics" within school halls of The United States for more than thirty years. The new basics commenced from a push for "more rigorous and measurable standards" (National Commission on Excellence in Education, 1983), increased credit requirements in high school, and a more concentrated curriculum across the country. Despite the numerous reforms enacted subsequent to this report, it is not clear whether these modifications have universally benefited all students. In fact, it has been posited that much of what is learned in secondary school is not applicable in the real world (Hurn, 1993). Simply put, students need more than what is commonly referred to as “the new basics.” Application of these basics in new and meaningful ways is the procedure of transferring school-learned skills into reality (Wiggins & McTighe, 2008). The same researchers stated that, in order to learn to understand, students must, “(1) acquire important information and skills, (2) make meaning of that content, and (3) effectively transfer their learning to new situations both within school and beyond it”.

It is thinking about this “meaning making” that leaves one wondering exactly how to help students make those connections. “Learning how to learn cannot be left to students. It must be taught” (Gall et al., 1990). While, metacognition is a seemingly new concept within the classroom, it is not a new idea on its own. Metacognition - sometimes simply understood as “thinking about one’s thinking” - has been a foundational inquiry into the way in which students process information since before John Flavell (1979) first named the idea. He stated that metacognition is made up of both metacognitive knowledge and metacognitive experiences. No new exercise, people have been reflecting on not only their thoughts, but their way of thinking, well before Flavell named this field of study. Flavell and others have shown that metacognitive techniques and strategies enhance learning. Learners that use these approaches to make and track their progress are more proficient at learning (Flavell, 1979).

Most schools focus solely on the attainment of rote information over the transfer and meaning making of learning. Limitations on time lead to the fact that, understandably, teachers often struggle to merely cover the curriculum in a given subject and year. To this end, many discussions are had, from conference rooms to break rooms, on breadth versus depth of content. As an example, consider an unfamiliar problem within learned content that was given to students such as the following high school algebra question from state tests in New York and Massachusetts:

> To get from his high school to his home, Jamal travels 5.0 miles east and then 4.0 miles north. When Sheila goes to her home from the same high school, she travels 8.0 miles east and 2.0 miles south. What is the measure of the shortest distance, to the nearest tenth of a mile, between Jamal's home and Sheila's home? (Students were provided with a grid they could use to plot the answer.) (Wiggins & McTighe, 2008, p. 36).

Interestingly, the 10th grade students from New York that took this test had a lower than 40 percent success rate on answering this question correctly. This is in direct contrast to the fact that this content is in the curriculum standards for algebra for each student across all of the United States. Clearly, the methodology failed these standards and/or the curriculum standards are not reflective of actual learning.

Because such an expanse exists between classroom achievement and the transfer of learning from one environment to another, the mission of educators should therefore be framed as follows: Instructors must enable students to not only learn information but transfer that information into knowledge and skills - not from year to year and test to test, but from the classroom to the real world. Wiggins and McTighe worked with this idea of transferring knowledge, and incorporated methods from their seminal work, Understanding by Design (2005), by starting a lesson or subject with a hook to draw students in, before introducing the essential questions. Their tiered approach then moved to meaningful practice in the middle of the lesson, followed by a penultimate activity of student performance tasks. Finally, the closing activity culminated in a reflection period whereby students were given space and time to answer the lesson's essential questions in their own words, complete with their own gathered evidence and reasoned conclusions.

As the Next Generation Science Standards (NGSS) sweep the nation, the push for practice over content, or rather content learned through practice, seems to parallel with this idea of student tasks. In fact, the standards themselves are called performance expectations and combine three dimensions of learning into each one. The disciplinary core ideas, the science and engineering practices, and the cross-cutting concepts are bundled together to drive what has been deemed to be essential science understanding for all students (NGSS Lead States, 2013). Honing in on the science and engineering practices, specifically, it should be made clear that these practices are inherently different from the solely inquiry-based classes that are currently taught (Padilla, 2010). This takes into account the fact that science learning can be messy and there is often not one correct way to uncover evidence. The word itself, practices, indicates this holistic approach. Like the scientific method, the practices are done as a multi-method approach to answer questions instead of the linear technique of: step one - state the problem; step two - make observations; step three - make a hypothesis; step four - complete an experiment; step five - draw conclusions (J. R. Allen, personal communication, 1994). In reality, science is comprised of flurries of activity, done in any order, with some often repeated. These practices are the heart of science itself (Duncan & Cavera, 2015).

There are eight specific science and engineering practices that are part of the three dimensions of the NGSS. As mentioned, these practices have often times been overlooked to push through the content but are essential in allowing students to become scientific thinkers, not just people who can regurgitate facts (National Research Council, 2012). The practices highlight skills and reason to demonstrate scientific understanding. In addition, they help students construct understandings of the other two dimensions to help transfer knowledge to new scenarios. These practices also allow the learner to simulate the actions of professional scientists and engineers. The eight practices are as follows:

1. Asking questions and defining problems
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 and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

(National Research Council, 2012, p. 49).

The question then becomes, how can educators fairly and regularly assess these science and engineering practices that students are now explicitly using? Traditional testing becomes unreliable in the face of scoring a performance: A survey completed by Sarah Boesdorfer (2016) showed that only 13.0 percent of teachers surveyed in Iowa implement and assess the engineering portion of the NGSS in their chemistry classrooms. The change in practice does not just arrive with a change in standards. Teachers need structured, regular, repeated, and scaffolded professional development in order to affect change on the curriculum and student learning. With this professional development, there is a marked increase in student activities that reflect the NGSS science and engineering practices (Hayes, Lee, DiStefano, et al., 2016). If teachers aren't teaching the material, it certainly cannot be assessed. The National Resource Council's Framework (2012), which was the foundation for writing the NGSS, is still relatively new. Only 16 states have adopted the standards as of 2016. However, over 40 states have shown interest in adopting them, so the trend appears to have taken hold. Unfortunately, of the few assessments published that purport to align with the NGSS, most are not of high quality, and fail to fulfill all three dimensions of performance expectations at each grade level (Pellegrino, 2013). Even with the understanding that standards-based instruction and assessment may enhance student learning, it has been shown that a mere change in curriculum standards alone does not automatically lead to a change in teachers' practices to fit the new standards (Donnelly & Boone, 2007).

Once the instruction and assessments are properly aligned with the NGSS, the growth of the practices will be in the spotlight. Teaching the practices separately is a difficult endeavor but reinforcing them and naming them are methods to encourage the ownership of them with students. While it has been shown that detailed and interactive student notebooks alone are not enough to ingrain these practices, metacognitive strategies are most helpful in affecting student process skills. Some skills that led to student success were written, conversational feedback, reflections, and conclusions (Mallozzi & Heilbronner, 2013). Notwithstanding this student success, the lingering issue remains of how to effectively make these practices habitual for students and teach fluency with them so that they become second nature for use in solving problems. It has been shown that metacognitive strategies help during test taking, often by a wide margin (Aurah, Cassady, & McConnell, 2014). This naturally leads to the conclusion that metacognition during instruction and exploration will help students with a deep understanding of the science and engineering practices. When students think about their process of thinking, learning becomes innate.

Conclusion

Research has clearly shown there is a need for students to transition from "learning about" to "figuring it out" (E. Brunsell, personal communication, 2017) with regards to understanding in science. Some preliminary research has been done around reflection on the model of inquiry to reinforce the NGSS science and engineering practices. Simply having students plot which practice or practices they used in the lesson can have a lasting impact on the meaning making of the activity (Nyman and St. Clair, 2016). This reflective routine is an avenue of education that warrants more exploration. The combination of metacognitive practices with the NGSS performance expectations might be the edge that students need to deeply make meaning from the world around them.

METHODOLOGY

The purpose of this study will be to increase the transfer of the science and engineering practices through the regular use of metacognition. The treatment for this Action Research project will involve metacognitive strategies through these eight practices of the NGSS. I anticipate completing this exploration through a nine-week quarter of the spring semester, which usually aligns with a whole unit of study.

Participating in this study will be 78 students, all of whom will be given the intervention. The students will be given pre and post assessments that test understanding and application of the science and engineering practices, a pre and post-intervention survey, and a post intervention interview of eight students.

Participants

Overall, my students are education focused, curious, and eager to learn and work hard. I teach four 65-minute classes of seventh grade students that range from 18-22 students each, for a total of 78 total students. We are on a block schedule with a seven-day rotation and I see each class four times per rotation.

Intervention

I have found a number of interesting methodological approaches that narrowed down the specific intervention used. One that was the most intriguing was the idea that dismantled the teaching of the scientific method in a linear progression (Harwood, 2004). This study echoed many earlier published works that began to break away from the rigid, step-by-step format of inquiry. It detailed a model of inquiry as a series of 10 exercises that scientists employ to answer a question, with the question in the center and the methods spread about in a circle around the question. This visual understanding allows a scientist to visit any method, in any order, and as many times as needed to answer the question. In an article by Matthew Nyman and Tyler St. Clair (2016), this method was modified for use with the NGSS, shown in Figure 1. The question was still in the circle's center, but now the outer points making up the circle were the science and engineering practices.

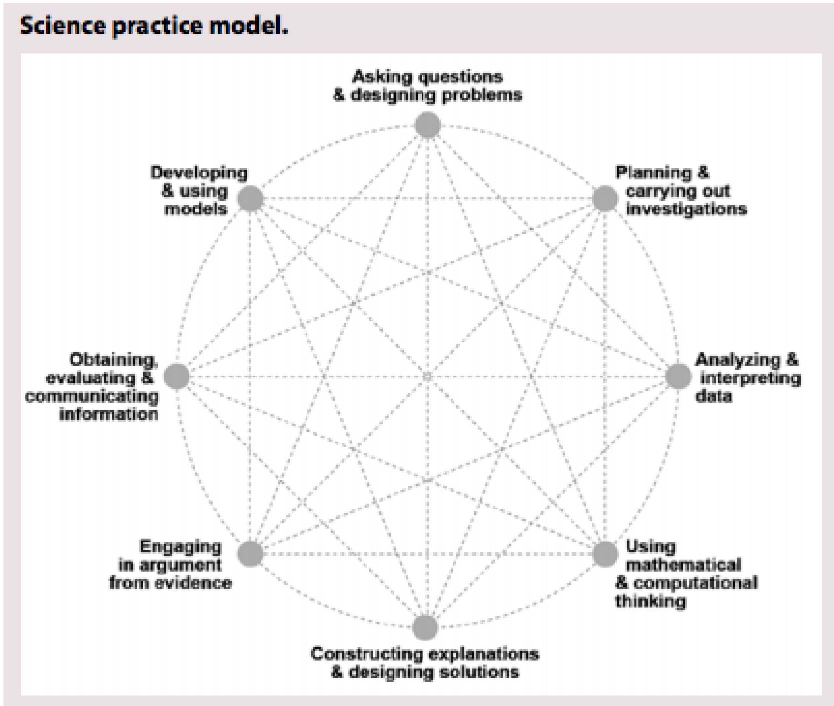


Figure 1. Science practice model (Nyman & St. Clair, 2016).

The idea for my action research project will be to use these circles to have the students map the practices that they have used during each lesson and activity. Students will trace their practice path from initial practice to their next practice and so on. They will tie in a small reflection piece with each circle where the student will write a sentence explaining how they used a practice or practices that day. Within the same research question, students will reuse the same circle. Students will have choice over how they track their practice during each lesson. Allowing them choice provides a bit of freedom with regards to colors or methods for their own metacognition. Between research questions they were encouraged to evaluate the way the tracked the practices and to decide if they would keep that method or change it for the next question. One criterion that I asked them to stick with was to keep the same method throughout a question for continuity. This will highlight how often students use a practice to answer the same question and will reaffirm to them that science is anything but linear. The aim of this research is to determine if students become more proficient with the practices if they purposefully think about which practice they are using. A transition will hopefully occur where students decide which practice is best to answer a research question instead of being directed by their teacher. An idea for further research will be to have students map which practice or practices they will use before each lesson, just by knowing the question that will be answered.

Data Collection

To test the progress and attainment of the students' understanding of the science and engineering practices, grades from assessments were analyzed before and after the treatment. Also, students completed a questionnaire with a Likert scale, rating their feelings of how well they can use and understand the practices before and after the intervention. The questionnaire also rated the enjoyment of the process and if they will likely continue to use it in the future, in science classes moving forward. The data from these surveys were analyzed quantitatively and were compared using a bar graph.

The treatment was started at the beginning of quarter three for all four of my classes. The assessment data from quarter one was averaged and compared to quarter two and the assessment data from quarter two was also averaged and compared to the average of the third quarter assessment data. Throughout the study, all 78 students were exposed to all eight practices that were utilized both in the classroom activities and on the formative and summative assessments. During the treatment, regular classroom activities took place, the only difference were the metacognitive activities at the beginning and end of each class. The non-treatment units were astronomy, history of the earth, classification of life and characteristics of life and the treatment units were human impacts and evolution. These data were analyzed using a variety of methods, including box and whisker plots and a student's t-test.

In addition to these formal evaluations, I will be using formative assessments to measure progress and understanding. I think the muddiest point and the one sentence summary (Angelo & Cross, 1993) will be the most illuminating to have a snapshot telling if the students are reflecting in a way that is meaningful. I will also be checking their circles as they do them and they will be heavily guided in the beginning while tracing their practice path. After the period of guidance with their circles, I will assess them to see if the accuracy of the practice tracking can also predict success on summative assessments.

Student interviews will also be completed after the intervention to determine understanding and transfer of the NGSS Science and Engineering Practices. Six to eight students will be interviewed that represent a cross-section of the classroom population. The Montana State University Institutional Review Board has approved this study. Table 1 summarizes the data collection methods in this project.

Table 1
Triangulation Matrix of Methods

Focus Question: How does the integration of metacognitive strategies impact student understanding and transfer of the NGSS Science and Engineering Practices?			
Sub-questions	Data Source		
Sub-question 1: What is the impact of metacognitive strategies on student understanding of the science and engineering practices?	pre-survey	post-survey	student assessments
Sub-question 2: How do students perceive the usefulness of the metacognitive strategies in relationship to understanding the science and engineering practices?	pre-survey	post-survey	interview

DATA AND ANALYSIS

The analyses of the data showed growth in understanding and application for my students through the Next Generation Science and Engineering Practices. This growth was determined both through the quantitative measures of assessment grades as well as their personal reflections through survey results.

Overall, students in the class did well on the assessments that were given throughout the research, with an overall mean of 87.2 for all three quarters. These scores were calculated solely on the times the students were assessed on the science and engineering practices, either on a performance-based assessment, traditional test or quiz, a lab, or a classroom activity. No additional grades, such as homework, participation, or vocabulary, were used in the classroom research.

The analysis of the pre- and post-intervention practice assessments between quarters one, two, three indicates there was statistically significant growth of students' understanding of the science and engineering practices from the NGSS by using metacognitive strategies. All classes (N=78) were able to utilize the treatment, so I compared the assessment data (gathered only through assessment of the practices, not content) from quarter one to the practices assessment data from quarter two. There was no intervention while the students were learning during this time. I expected some growth to occur naturally because of skill development through regular classroom activities. After the intervention, I compared quarter two to quarter three assessment results to see if the growth was analogous to quarters one and two. The normalized gain between quarters one and two was 3.0%, showing expected skill development. The normalized gains between quarters one and three and two and three were 37.8% and 39.6%, respectively (Table 2). This shows that students have more deeply understood the science and engineering practices through the metacognition treatment and can use them accurately in new scenarios.

Table 2
Class Averages of the Science and Engineering Practices Assessments and Normalized Gains From Quarters One, Two, and Three (N=78)

	Quarter 1	Quarter 2	Quarter 3
Class Average	85.0	85.5	91.0
Normalized Gains Between Quarters 1 and 2 (no intervention)		3.0%	
Normalized Gains Between Quarters 2 and 3 (with intervention)		37.8%	
Normalized Gains Between Quarters 1 and 3 (with intervention)		39.6%	

The results indicated a growth in proficiency across the practices after the intervention, as shown in the class means, but also showed tightening up of the range and standard deviation for each quarter (Table 3).

Table 3

Class Ranges and Standard Deviations of the Science and Engineering Practices Assessments From Quarters One, Two, and Three (N=78)

	Range	Standard Deviation
Quarter 1 (no intervention)	45.9	9.7
Quarter 2 (no intervention)	36.7	8.3
Quarter 3 (with intervention)	29.2	5.1

When examining the student data using graphical analysis, a box and whisker plot was used to show the pulling together of the spread of range and the increase of mean in the quarter after the treatment (Figure 2).

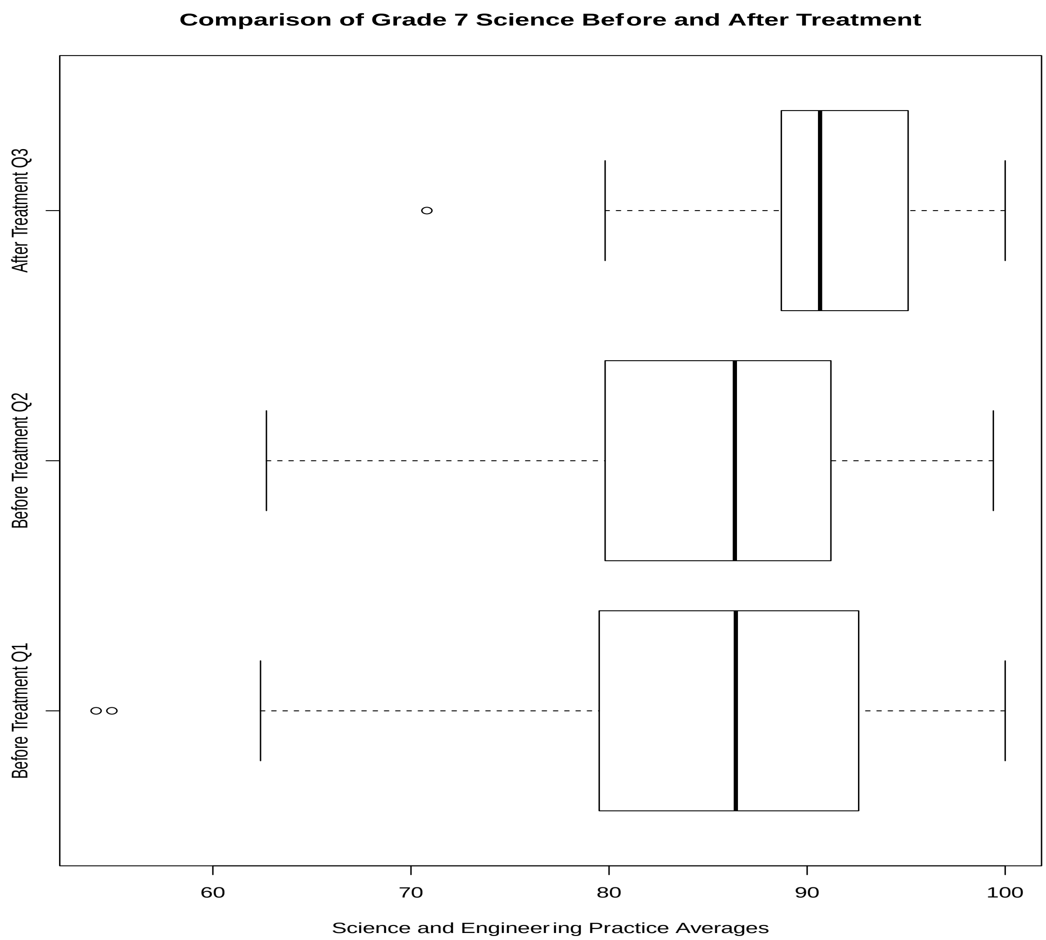


Figure 2. Distribution of scores on science practices assessments for quarters one, two, and three, (*N*=78).

After the calculation of the mean, standard deviation, and graphical analysis were completed, I administered a student's t-test to determine if the gains were statistically significant (*N*=78). I wanted to determine confidence to conclude that the growth between quarters with and without treatment were different and not just happenstance. The result of the t-test between quarters one and two (with no intervention), is t(154) = 0.3070 which has a p value = 0.7592. This does not show statistical significance between the growth of quarters one and two. The t-statistic from quarter one to three (with intervention) is t(154) = 4.7627 which results in a p value of less than 0.0001. This shows statistically significant growth between these two quarters. A final comparison between quarters two and three (with intervention), again showed statistical significance with a result of $t(154) = 4.9869$ giving a p value of less than 0.0001.

During the analysis of the student survey data, I concluded that students showed growth of confidence in their skills of the science and engineering practices with the exception of identifying how to ask a scientific question. The percentage of students that agreed to that before the treatment was 90.5% and that dropped to 87.2% after the treatment, a difference of 3.36% lower. The rest of the results of the survey with regards to confidence in the practices showed growth (Figure 3). The highest growth shown was in the confidence of using mathematics and computational thinking with an increase of 19.47%. Students did not have much experience with this skill before the third quarter of seventh grade, so the low confidence rating given by students at the beginning of the intervention makes sense. Their math skills as well from their math class dovetailed with science quite often, so they built this skill up rather quickly. The two skills with the most student confidence was found to be analyzing and interpreting data and obtaining, evaluating, and communicating information, both with a student confidence percentage at the end of the treatment of 96.15%.

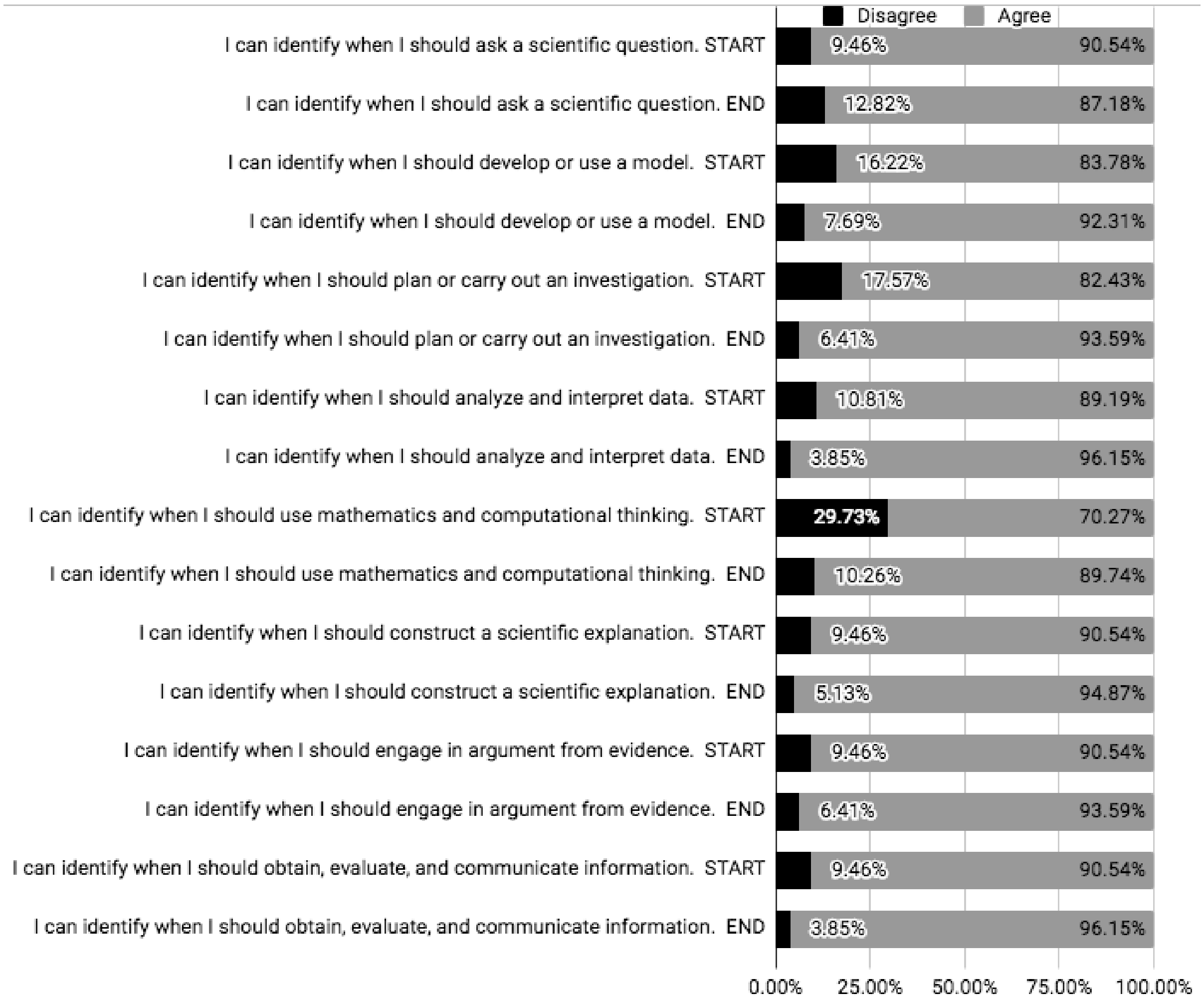


Figure 3. Student survey results on their confidence in using the practices, (*N*=78).

Given the results of the assessments between quarters before and after the intervention, as well as the student confidence survey outcome, I do think that the metacognitive strategy of using the practice tracker each class has a positive impact on student learning.

The other question that was posed asked how students perceived the usefulness of the metacognitive strategies in their understanding of the science and engineering practices. To answer this, I looked to the self-reporting survey results as well as my interviews with eight students from the class. After the intervention, 80.77% of students reported that they felt more confident in their understanding of which practice they were using during class. This was an increase of 11.85%. A small majority of the students reported that they enjoyed using the tracker, only 58.97% completely agreed with that statement and 19.23% strongly agreeing (Figure 4). One student reported, "I don't see why we need to write down which practice we are going to use before and after we use it, we are wasting time when we could be actually doing the practice!" Another student stated, "It seems like it's a bit of a waste of class time, no offense Ms. Monroe." However, another student responded, "The tracker helps me focus my energy during class and I have a better scope of what we'll be doing, that way I can take action during our labs knowing which skill to rely on."

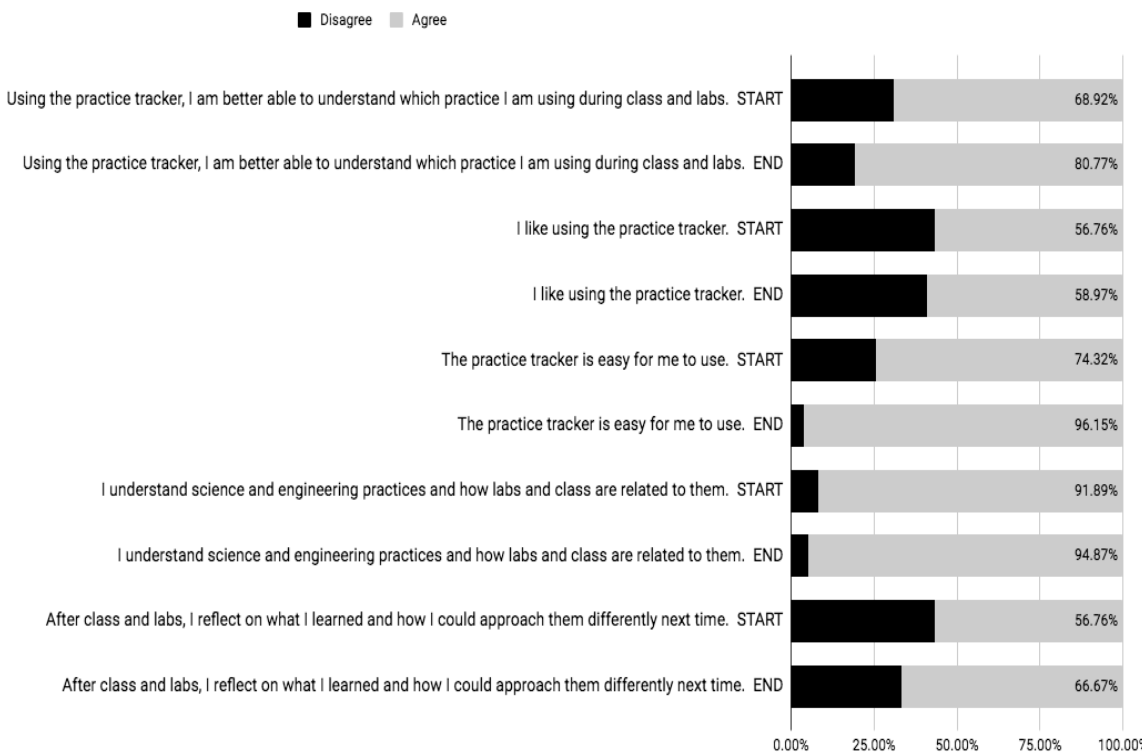


Figure 4. Student attitude survey toward the practice tracker, (*N*=78).

From the attitude survey, 66.67% of students reported that they reflected on what they learned and how they could approach labs and activities differently the next time. This increased from 56.76% of students that reflected before the treatment, an increase of 9.99%. When asked in the interview, one student reported, "I feel like science class lingers with me a little bit longer throughout my day" and "I talk about science more at the dinner table at night since using the practice tracker."

Considering that these results did not show as dramatic of results as the assessment data, I consider the results to show that most students did perceive the metacognitive strategies were useful to their understanding and enjoyment of the science and engineering practices. When asked if she would continue using the practice tracker throughout the year and with other science classes, a student reported that "I have developed a color-coding system that helps me know my confidence in the skill the last time I used it. I feel like I'm in control of my learning and understanding, and I will definitely keep using it."

As shown, students' understanding and application of the Next Generation Science and Engineering Practices were measured, evaluated, and analyzed. By using the metacognitive strategy of a daily practice tracker, students showed considerable growth without a large loss of class time. Students were given choice about how they tracked their practice, which enhanced their buy in with the intervention.

INTERPRETATION AND CONCLUSION

This research project had the lofty goal of growing students' confidence in and ability to use the Next Generation Science and Engineering Practices through the assessments of their classroom activities, labs, projects, and tests. There is limited research using metacognition and the NGSS practices, (Mallozi & Heilbronner, 2013). I'm certain this will change soon, as science is rapidly becoming "the cornerstone of 21st century education" (Michaels, Shouse, & Schweingruber, et al., 2008, p. 2). The other question addressed how students perceived the strategy; did they find it useful and enjoyable?

As Dewey (1910) theorized, meaningful learning happens when reflection is an integral part of the process. The results of this research confirm that claim. Examining the understanding of the growth with the practices through assessments, it is obvious that students showed considerable and significant gains through comparison of different grading quarters when there was no treatment to when students participated in the regular metacognitive tracking of the science practice(s) during the class. With educational research, it is difficult to control all possible variables, but a reasonable attempt to do so was completed with care. Students used different modalities of learning throughout all learning quarters, the same teacher (style of instruction), same lab assessment styles, same format of unit tests, with the only overt differences being the different concepts and, of course, time. To discount natural growth through repeated use would be ignorant, but this is the reason I compared quarters one and two (with no intervention) as well, in addition to the quarter where the treatment was implemented.

When I began this research, I was laser-focused on assessment growth, and didn't put much thought into the growth of the students' confidence with the practices or enjoyment of them. Observations throughout the treatment quarter led me to draw some anecdotal conclusions. Students started to notice trends. For instance, I was trying to build their modeling skills and by the third class meeting, students would comment that we had been using that practice frequently. I also notice they started appreciating the subtleties of the practice titles, developing and using models, for instance. They could discern which one was used during a class and start to recognize that there are different types of models. Another skill this happened with was obtaining, evaluating, and communicating information. We were doing a research project and I noticed that students started reflecting on which part of the skill we used in class that day and could discuss it as parts of a whole. The metacognitive parts of class, where they tracked their practice and when they reflected at the end grew shorter and shorter, but I feel the quality of each increased as their understanding of the practices grew.

The interpretation of the usefulness survey was most surprising to me. The students I teach, for the most part, genuinely value learning and are inherently, and sometimes relentlessly, curious. They embraced the use of the practice tracker, listened carefully while I explained its purpose and proposed value, and had meaningful contributions about what metacognition is and why it can be useful. So, I was pretty surprised with the results of the survey showing that only 58.97% enjoyed using the tracker after the treatment time was over. It wasn't an intrusive part of class, and I made it part of our daily routine. I plan on sharing the results of the intervention with them and seeing what they think after they see that it had a positive and significant affect on their assessment grades. My students are very focused on scores and doing well in school, so I wonder if the value is adopted first, the enjoyment can come later. Or, if this is an exercise in doing something just because it is good for you not because you like it, like running is for me.

Examining the survey for the students' perception of the usefulness of the practice tracker reflected that, for the most part, students thought that their understanding of science skills deepened. The only one that didn't grow was asking scientific questions. This led me to examine how often each practice was used that quarter. This is not something I knew from the beginning of the year. I have the scope and sequence of the school year planned out regarding performance expectations, but as far as individual lessons went, I wasn't planned out far in advance as this was my first year at my school. I examined each learning progression building up to the performance expectation and saw that during the intervention quarter, asking scientific questions was only practiced once and not assessed at all. The first quarter it was practiced six times and assessed twice. I believe this explains the students' lack of confidence with this skill.

The focus of my year with my students has been firmly rooted in the engagement of the science and engineering practices through the disciplinary core ideas. Planning meaningful, real world lessons that engage the students and provide them a chance to use the skills to solve problems and answer questions. The academic success of the students was supported through their metacognitive strategies of using the practice tracker, reflecting on their learning, making meaning of the concepts, and focusing on the transfer of skills from one application to another. These results are supported by plenty of metacognitive research in education (Aurah, Cassady, & McConnell, 2014; Dewey, 1910; Flavell, 1976; Mallozzi & Heilbronner, 2013; Nyman & St. Clair, 2016; Pintrich, 2002;

Tanner, 2012). This determination is also congruent with work by Padilla (2010) that states using science process skills allows for the transformation of receiving knowledge to being able to apply knowledge. Padilla goes on to state that while all students are interested in being excited by hands-on science, learning happens when students are thinking about the process of science while they do it.

VALUE

This endeavor has brought me to a different level in my teaching practice. While I faced some difficulties in the initial implementation of my intervention, they were overcome with patience and problem solving. Moving schools right before my research was planned wasn't ideal, but I believe it worked out very well. It helped that the students in both schools were very similar and that I have a lot of agency and freedom by the administration to design and implement the curriculum in the best way I see fit.

I went into this experiment completely open to all possibilities. Knowing that educational research can be notoriously difficult to conduct gave me some freedom to take risks without worrying about the results. It helped that I chose my topic quite organically through a journal article I read even before we needed to whittle that down. I believed in what I was doing, I had the research to back up the reasoning, and the knowledge from colleagues, professors, and peers that I would conduct the research, gather the data, and analyze it well.

Before this research, I had no formal metacognitive strategies in place in my classroom. I used reflections as a tool, as well as self-assessments of learning. But, they were haphazardly implemented and weren't focused on the overarching transfer goals of budding middle school scientists. I feel confident that my classroom aims are focused on the practices through the content, but I haven't measured how the students make meaning from them.

This research has also provided me with insight regarding how important it is to simply ask students how they are doing. We feel like we assess them to find this out, but they themselves are the experts with regards to articulating their learning. And, more importantly, they are the specialists when it comes to knowing how they learn. I have always done an end of year reflection with my students, but this process has taught me that I need to check in with them more often. This will help to get a baseline heartbeat of understanding from the students themselves. When coupled with assessment data, this is a very powerful form of evaluation. When they are aligned, everyone in the boat (teacher and student alike) is rowing in the same direction, but when they are not, some adjustments must be made.

Ultimately, this reinforces what I believe is at the heart of teaching middle school science. I want my students to love science. I want them to know they are good at science and they can continue to be good at it. I used to teach high school and it was so easy to teach the kids that loved science, and so hard to convince the ones that didn't that they could love it. I have also taught elementary students, and they all love science because at that age it is still magic and fun and full of possibilities. I have found that middle school is where we can lose them. Middle school seems to be where they decide if they are 'good' or 'bad' at science. It becomes less about awe and excitement and more about grades and equating those with if they can still be passionate about a subject.

This metacognitive practice gives the power of learning back into the hands of the student. It puts them in the driver's seat. It gives them ownership and that can allow passion to flourish. Not many students come to me in seventh grade that aren't amazed by science, I want even fewer to leave that way. This teaching practice of using metacognition, giving voice and choice to how the students implement it, and focusing on the skills of a scientist are ways that my practice will continue because of this research project.

Despite my data collection coming to an end, I have still maintained the use of the practice tracker each class. It has become a habit of mind to my students and they do it without prompting. We changed units and I didn't immediately pass out a new practice, as I had been doing during the research, students in each class immediately raised their hand to remind me. That speaks to how ingrained this has become, and how useful the students feel it is.

I also learned a tremendous amount through the interviews with my students. I knew that they cared about their learning, but I didn't know how much thought they put into it. They had valuable things to say, and I never would've heard them if I hadn't asked. They were candid and real with me, and I cherish that they trusted me enough to be open. They expressed their understanding of my care for their learning and showed compassion and curiosity for the process.

I'm not sure how to work that interview process into my regular year in an authentic way, but it was so insightful that I feel as though I need to. Our school has student-led conferences toward the end of the year, and I think that a learning interview before this will be helpful to both student and teacher.

Overall, the students grew through this research project and so did I. Some changes that I plan on making are to be clear with the growth of the practices through the year. This year was difficult since I didn't have my learning progressions clearly in place before it began, but next year will be easier since I can just workshop my lessons instead of creating them as I go. Ideally, I'd like to see a spiraling of the skills through the year that makes sense sequentially. I do still plan on using the practice trackers as part of my daily lesson. There isn't much I will change with regards to the use, but I am thinking of turning them into a booklet that has the reflection questions inside. The reflections were a bit disjointed since they were done in the students' notebook and didn't seem as though they were a part of the tracker itself. I will certainly share my results with my current and future students. My biggest takeaway from this is that kids love knowing why they are doing things in class. They don't like their time wasted and will readily adapt new structures when they see value and have an explanation.

REFERENCES CITED

Angelo, T.A., & Cross, K. P. (1993), *Classroom assessment techniques: A handbook for college teachers.* San Francisco: Jossey-Bass Publishers.

Aurah, C. M., Cassady, J. C., & McConnell, T. J. (2014). Genetics problem solving in high school testing in Kenya: Effects of metacognitive prompting during testing. *Electronic Journal of Science Education*, 18(8).

Boesdorfer, Sarah B. (2016). Teachers' Practices in High School Chemistry Just Prior to the Adoption of the Next Generation Science Standards. *School Science and Mathematics*.,116(8), 442-458.

Dewey, J. (1910). How we think. Boston: D.C. Heath & Co..

Donnelly, L. A., & Boone, W. J. (2007). Biology teachers' attitudes toward and use of Indiana's evolution standards. *Journal of Research in Science Teaching*, 44(2), 236-257.

"Facts at a Glance." *About Menlo,* www.menloschool.org/about/facts-at-a-glance.php.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, 34, 906-911.

Flavell, J. H. (1987). *Speculations about the nature and development of metacognition*. In F. E. Weinert & R. H. Kluwe (Eds.), Metacognition, Motivation and Understanding (pp. 21-29). Hillside, New Jersey: Lawrence Erlbaum Associates.

Gall, M. D. (1990). *Tools for learning: a guide to teaching study skills*. Alexandria, VA: Association for Supervision and Curriculum Development, 7.

Garner, R. (1990). When children and adults do not use learning strategies: Toward a theory of settings. *Review of Educational Research*, 60, 517-529.

Golan Duncan, R., & Cavera, V. (2015). DCIs, SEPs, and CCs, Oh My! Science and Children, 053(02), *Science and Children*, 2015, Vol.053(02), 67-71.

Haag, S. and Megowan, C. (2015), Next Generation Science Standards: A National Mixed-Methods Study on Teacher Readiness. *School Science and Mathematics*, 115: 416–426.

Harwood, W.S. (2004). A new model for inquiry: Is the scientific method dead? *Journal of College Science Teaching*, 33(7), 29-33.

Hayes, K.N., Lee, C.S., DiStefano, R. et al. *Journal of Science Teacher Education*, (2016) 27: 137.

Hurn, C. J. (1993). *The limits and possibilities of schooling: an introduction to the sociology of education*. Boston ; Toronto: Allyn and Bacon.

Lontok, K. S., Zhang, H., & Dougherty, M. J. (2015). Assessing the Genetics Content in the Next Generation Science Standards. *PLoS One*, 10(7), e0132742.

Mallozzi, F., & Heilbronner, N. (2013). The Effects of Using Interactive Student Notebooks and Specific Written Feedback on Seventh Grade Students' Science Process Skills. *Electronic Journal of Science Education*, 17(3), 1-22.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, Set, SCIENCE: Putting research to work in the K-8 Science Classrooms.* Washington, D.C.: The National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioural and Social Sciences and Education. Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States*. Washington, D.C.: National Academies Press.

Nyman, M., & St Clair, T. (2016). A Geometric Model to Teach Nature of Science, Science Practices, and Metacognition. *Journal of College Science Teaching*, 45(5), 44-50.

Padilla, M. (2010). Inquiry, process skills, and thinking in science. *Science Scope 19*(2), 8-9.

Pellegrino, J. W. (2013). Proficiency in science: Assessment challenges and opportunities. *Science*, 340(6130), 320-323.

Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and assessment. *Theory into Practice, 41*(4), 219-225.

Tanner, K. (2012). Promoting student metacognition. *CBE Life Sciences Education*, 11(2), 113-20.

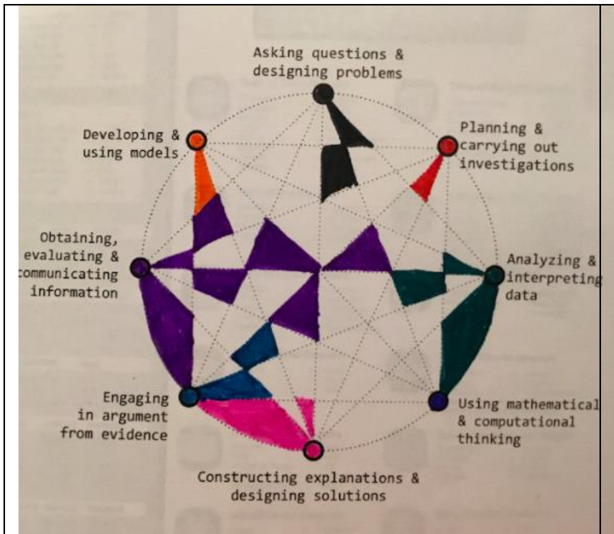
United States. National Commission on Excellence in Education. (1983). *A nation at risk : the imperative for educational reform : a report to the Nation and the Secretary of Education*, United States Department of Education. Washington, D.C. :The Commission : [Supt. of Docs., U.S. G.P.O. distributor].

Wiggins, G., & McTighe, J. (2008). Put understanding first. *Educational Leadership*, 65(8), 36-41.

APPENDICES

APPENDIX A

STUDENT PRACTICE TRACKERS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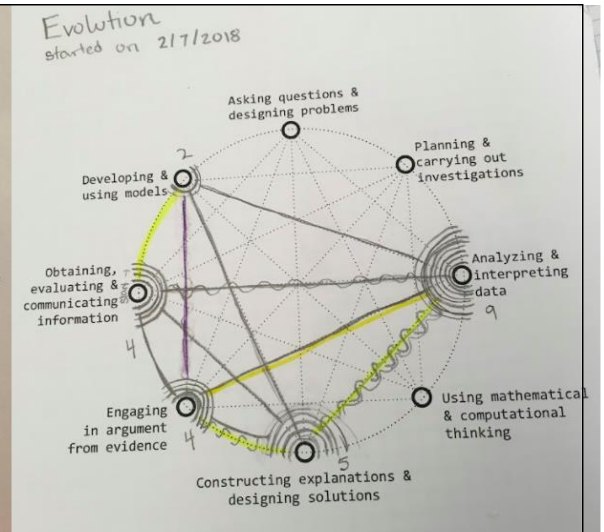
Planning & carrying out investigations
Analyzing & interpreting data
Using mathematical & computational thinking
Constructing explanations & designing solutions
Engaging in argument from evidence
Obtaining, evaluating & communicating information
Developing & using models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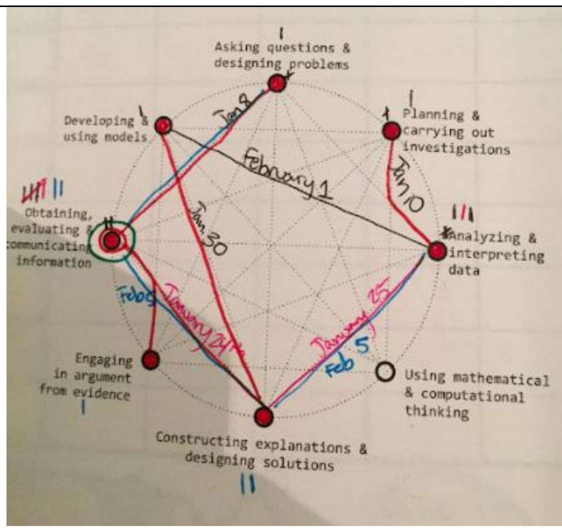
Developing & using models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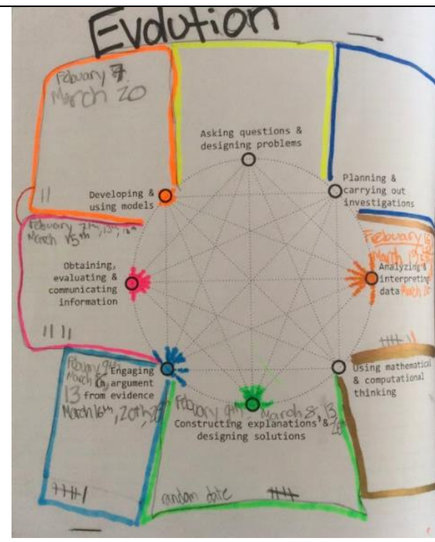
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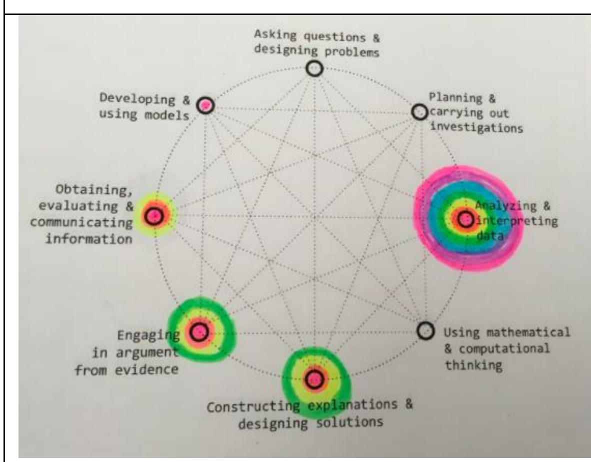
March 20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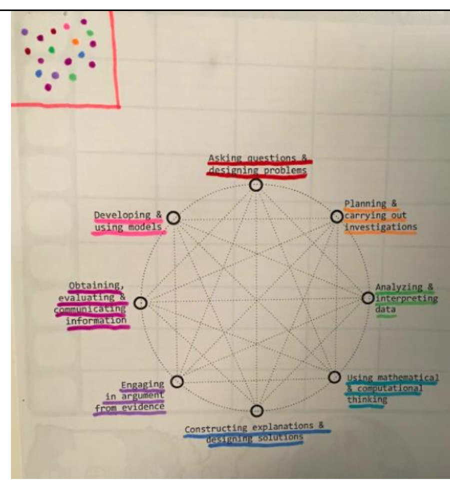
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APPENDIX B

STUDENT SURVEYS

Student Attitude Survey

Taking this survey is voluntary and participation or non-participation will not affect your grades or standing in class in any way.

Rate your abilities in each of the following questions using this scale. Circle the number below the question.

1 = I strongly disagree with this statement.

2 = I disagree with this statement.

3 = I agree with this statement.

4 = I strongly agree with this statement.

1. Most of the time, I understand what I am supposed to be learning during labs and class.

   1 2 3 4

2. I can identify when I should ask a scientific question.

   1 2 3 4

3. I can identify when I should when I should develop or use a model.

   1 2 3 4

4. I can identify when I should plan or carry out an investigation.

   1 2 3 4

5. I can identify when I should analyze or interpret data.

   1 2 3 4

6. I can identify when I should use mathematics and computational thinking.

   1 2 3 4

7. I can identify when I should construct a scientific explanation.

1 2 3 4

8. I can identify when I should engage in argument from evidence.

1 2 3 4

9. I can identify when I should obtain, evaluate, and communicate information.

1 2 3 4

10. By using the practice tracker, I am better able to understand which practice I am using during class and labs.

1 2 3 4

11. I like using the practice tracker.

1 2 3 4

12. The practice tracker is easy for me to use.

1 2 3 4

13. I understand the science and engineering practices and how labs and classes are related to them.

1 2 3 4

14. After classes and labs, I reflect on what I learned.

1 2 3 4

APPENDIX C

STUDENT INTERVIEW QUESTIONS

Post Treatment Interview Questions

Taking part in this interview is voluntary and participation or nonparticipation will not affect your grades or standing in class in any way.

1. How did identifying the science practices help you understand concepts in class and labs?
2. Did you find the process of identifying the science practices easy without the tracker?
3. Did using the tracker help you recognize the practices more?
4. How did using the tracker affect your science understanding?
5. Were you consistent in using the tracker before and after classes and labs?
6. Describe your confidence level in science before using the tracker, and after using the tracker for two months.
7. How well do you understand which practice you use during classes and labs?
8. Do you like using the practice tracker?
9. Is the practice tracker easy to use?
10. Will you continue to use the practice tracker in future science classes?