

# The Great Ice Investigation: Preparing Pre-Service Elementary Teachers for a Sensemaking Approach of Science Instruction

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## Abstract

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The current article describes a sequence of lessons, readings, and resources aimed to prepare elementary preservice teachers for science instruction wherein student sensemaking, rather than vocabulary memorization, is prioritized. Within the article, I describe how the prompts, questions, and logistics of the The Great Ice Investigation drive my students' in-class and out-of-class learning to start out every science methods course I teach. The readings and resources detailed that compliment the Great Ice Investigation should benefit both preservice as well as in-service elementary teachers just beginning to align their instruction with the Next Generation Science Standards. The lessons, readings, and resources described should be of value to science teacher educators looking to modify and improve how they prepare their students for next generation science instruction.

## Introduction

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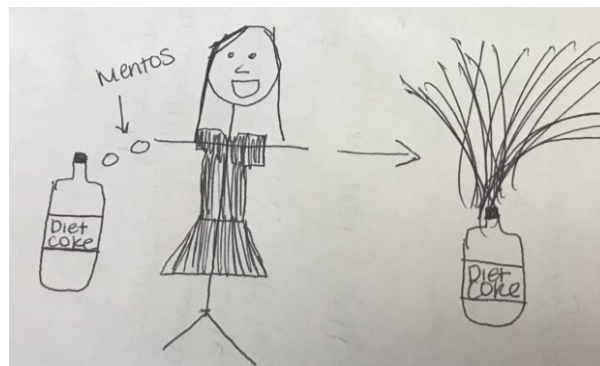
Many elementary science classrooms have not yet transitioned teaching and learning to meet the expectations of Next Generation Science Standards [NGSS] (NGSS Lead States, 2013). Due to this predicament, science teacher educators will remain responsible for initially preparing pre-service science teachers [PSTs] during this transition period. The NGSS represent a contrasting view of science instruction to the vision most PSTs have likely experienced in the past, which will make the transition all the more challenging. In order to help the PSTs in my elementary science methods course, I developed a series of lessons aligned with the guiding assumptions of the *Framework for K-12 Science Education* (National Research Council [NRC], 2012) to help overcome potentially counterproductive beliefs that may stem from my students' past experiences in science classrooms. The current article describes the sequence of lessons, readings, and resources I have used to begin my science methods course with the aim being to help the PSTs I work with to view NGSS-aligned instruction as primarily about student sensemaking. Additionally, the article highlights the alignment of assessment design with classroom instruction and also emphasizes multi-dimensional science learning by targeting applicable scientific practices (e.g. *Asking Questions*; NRC, 2012). In general, the series of experiences takes roughly three weeks, given each class lasts at least two hours. Additionally, the sequence of lessons introduces my students to multi-dimensional, NGSS-aligned science instruction with a particular focus on the practices of science.

## Drawing Out Past Learning Experiences

Prior to the first class, I require students to watch a recent video from *PBS News Hour* (<http://www.pbs.org/newshour/bb/in-elementary-education-doing-science-rather-than-just-memorizing-it/>) that introduces students to the NGSS by detailing how teachers in Wyoming have been transitioning to the new standards. In brief, the news clip helps students understand change is on the horizon across the country and that for most teachers, the *science and engineering practices* [SEPs] of the NGSS represent a major driver of that change. In addition to discussing the video during the first class, I ask students to draw a positive science learning experience from their past using the following prompts adapted from Van Zee and Roberts (2001): (1) *Think about some of the better experiences you have had as a science learner. Please choose and draw a picture of this experience in the space below. Include a caption for your picture.* (2) *What factors were important in fostering science learning for you in this instance?* (3) *What experience(s), knowledge, and interest(s) did you bring into this example that may have contributed to it being a positive experience?* Asking students to draw and reflect on a positive experience enables us to begin discussing instructional practices and teacher moves that contributed to making the experience memorable.

After students individually complete their drawing, they partner up in small groups to share and compare their drawings. From here each group creates a large white-board presentation that overviews the group's positive science learning experiences. Eventually, we all view each group's poster during a whole-class "gallery walk". Most students' past "positive" experiences include the phrases "hands-on" and "engaging". Additionally, their drawings depict field trips, dissections, explosions (c.f. Figure 1), and challenge-based competitions. After calling the class back together and prompting them to reflect on the frequency of these experiences most acknowledge how infrequent such experiences occurred. With students now thinking they might have missed out on the real value and purpose of K-12 science education, I promise them that by the end of this course they will have a newfound vision of what a positive science learning experience could and should be.

*Figure 1 (Click on image to enlarge).* Example positive science learning experience depicting an explosion.



## Eliciting Initial Ideas

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Starting off the *Great Ice Investigation* is a phenomenon-based lesson adapted from the *Exploratorium*. The lesson (titled *Inverted Bottles* – <https://www.exploratorium.edu/snacks/inverted-bottles>) is relatively simple to set up and elicits student thinking directly aligned with the forthcoming experiences. During the lesson, I prompt students to first *predict* the outcome of placing two glass bottles without caps, one with warm water (colored red with food coloring) and one with cold water (colored blue with food coloring), opening-to-opening with the warm-water bottle being placed on top of the cold-water bottle. Students commonly predict the warm water will remain on top of the cold, but cannot provide evidence beyond memorized facts such as warm things are lighter. After making their predictions, I then ask students to write down and draw what they *observe* happens. After the warm, red-colored water remains in its original bottle (on top), they respond to the prompt: *Explanation – What do you think caused this to happen?* Students then share their responses with an “elbow partner” prior to moving on. With the alternative set-up ready (cold water on top), we again follow the same sequence of prompts. From here, I continue to elicit and record students’ ideas as we try to make sense of the phenomenon just witnessed. During this time, I make sure not to validate any ideas as correct or incorrect while also asking various probing questions that might enable me to better understand their initial, prior conceptions (e.g. *What makes you think that? Where did you get that idea from? When you use that word, what do you mean?*).

## Using a Discrepant Event to Develop a Testable Question

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From here, I continue to *engage* students in a related phenomenon, but this time for a different purpose. I begin by briefly discussing the role of observations and questions in scientific inquiry and mention a quote from a former mentor that leads us into our next sensemaking event (*Science is a search for patterns.*). Each pair of students is provided with two 250ml plastic beakers. From here, they are introduced to the remaining materials: *room temperature tap/salt water* and *ice cubes*. Pairs of PSTs are prompted to first predict which liquid (salt or tap water) will melt a relatively similar sized ice cube first. During the observation period (~5 minutes), they need to time and record written observations (including simple drawings) in their science notebooks as each ice cube simultaneously melts in two different beakers of water. While this is happening, I circulate around the classroom asking students which beaker will melt the ice cube first as they watch this slow-moving “race”. Additionally, I ask students to explain the reasoning behind their predictions. Approximately 75% of students predict the ice cube in salt water will melt the ice cube first, which they typically explain is based on their past experiences melting ice in the winter with “sidewalk salt”. After each and every ice cube melts faster in the tap water beaker, we discuss the “results” of our simple investigation. Most are surprised the saltwater solution failed to melt the ice cube faster and oftentimes I am asked if I have deceived them somehow. I reiterate I have not and then suggest we use this experience to develop simple, testable questions that we can try and answer with yet another investigation.

As Reiser et al. (2017) suggest, in an NGSS-aligned classroom students need to raise phenomenon-driven questions in order to move a given inquiry forward. Additionally, Reiser et al. (2017) note, teachers will “need to probe and help students refine their questions to expand on things they take for granted and to help them see that there is something there that they can’t explain” (p. 93). I therefore provide students with the following sentence frames: “I wonder why...”, “What would happen if...”, “Next time if...” to encourage wonder and spur continued investigation. From here, each pair is prompted to complete a handout with the following prompts” (1) *Testable Question(s)* (2) *What sparked your interest in pursuing this?* (3) *Proposed Needed Materials (bulleted list/number requested)*. I do not provide students with specifics guidelines quite yet for writing their testable question because few have had prior experiences actually setting up dependent/independent/control variables. Typically, students pose a variety of related, yet slightly different questions to pursue. For example, students often ask questions related to the amount of water in the beaker, the temperature of the water, the make-up of the ice cube (i.e. salt water or tap water), the position of the ice cube in the beaker, or the use of liquids other than water (e.g. milk). Each and every question is eventually “approved”, given students have not requested materials I do not have readily available or that they are willing to provide themselves. I then let students know we will run their investigation during the next class and I will bring in the materials requested to do so.

## Between Class Readings

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Before the next class I assign two readings. The first (titled: *Why Teach Science? What Science Should We Teach?*; Harlen, 2015) is the introductory chapter to the assigned book for the course. Without describing the contents of the chapter in too much detail, in brief it provides students with three case studies portraying science instruction that aligns with the following *features of effective science teaching*: (1) Student Engagement (2) Materials for Investigation (3) Linking to Preexisting Ideas (4) Student Talk (5) Developing Inquiry Skills (5) Planning (Harlen, 2015). Additionally, I use a Web 2.0 tool (<https://flipgrid.com/>) – wherein students record video responses to each of the following prompts (with responses lasting no longer than 90 seconds):

(1) How does the view of science learning for young children match or contradict your own science experiences as a learner? Use specific examples from your life and specific ideas/examples from the reading...

(2) What challenges do you envision for yourself in creating a learning environment that aligns with the view of science learning put forth in chapter 1? What excites or frightens you about creating a learning environment of this nature?

Finally, I provide a response to each student’s video and also encourage peer-to-peer responses. In sum, I am more prepared to respond to my students’ needs after listening to their responses to these prompts because it elicits their previous experiences as science

learners, which they compare to the ideas presented in the reading as well as a peer's video responses.

The second reading details the purpose of *Disciplinary Core Ideas* [DCIs] (Duncan, Krajcik, & Rivet, 2015), which is a phrase most are unfamiliar with given the newness of the NGSS. Again, in brief, the reading details why DCIs are included in the NGSS and also describes how DCIs should be used in combination with other dimensions of the standards. Each of these readings and short “homework” prompts (via Flipgrid) help my PSTs envision how science learning could and should be implemented in elementary classrooms.

## Running the Great Ice Investigation

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Prior to class I re-type every investigation question (as originally written) students previously generated. I number groups of students off and assign them three or so other group's questions to examine. I prompt students to determine what each group is suggesting will be changed in their investigation, what will be measured, and what will be maintained (within reason) or controlled. Afterwards, we discuss how in order for each question to be *testable* it should contain an independent and dependent variable. After clarifying the difference between the two most groups quickly recognize if their question needs to be adjusted. For example, oftentimes students generate questions that contain multiple independent variables (e.g. type of liquid and temperature). Given the right type of support, students usually move on rather quickly once they recognize only one variable can be changed during their investigation.

From here, each group is introduced to the concept of a scientific hypothesis, which most believe is an educated guess. I suggest a hypothesis more likely represents an *idea that can be tested*, rather a mere guess. As an example, again, a group of students may be interested to find out if increasing the salt contents of multiple water solutions will gradually decrease the melting time that elapses – given the results of the first investigation. Some students better understand the purpose of a hypothesis after I introduce them to a “null hypothesis”. Briefly stated, if data from this hypothetical investigation uncovered that the melting rate remained constant despite the increased amounts of salt added to each solution then the null hypothesis would be supported. After students have adjusted their question, written a hypothesis, and prior to running their investigations, they must write out the steps of their soon to be conducted investigation. Providing students with hot water is the main safety concern when running the investigation. Aside from this, minimal concerns should arise given the parameters of the investigation.

Once each group has completed collecting their data, each group shares out their results, which we record for all to see. Student groups report out their independent variable (e.g. sugar in solution) and final results. At this point I want to ensure everyone begins to realize we all investigated the same phenomenon, and that our separate inquiries could be useful for making sense of the *inverted bottles* demonstration we discussed last week.

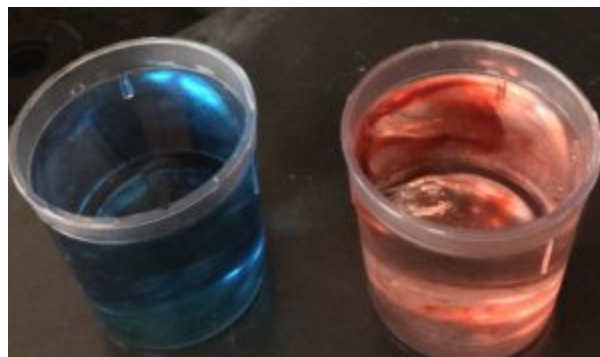
## Bringing Density into the Discussion

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From here, and in order to connect our in-class investigations with a related, real-world phenomenon, we start thinking more broadly about ocean water movement and its influence on global weather patterns (NRC, 2012). We therefore need to discuss water density and its impacts on the global cycle of water in the oceans. In order to understand how water density influences this large-scale phenomenon, you must first understand how variations in salinity and temperature influence the movement of water around the globe. However, and in line with Bybee's (2014) suggestion to infuse learning experiences driven by the NGSS with the "5E Learning Cycle" (*Engage, Explore, Explain, Elaborate, Evaluate*), I had not yet prompted my students to think about water density when initially carrying out their first investigation. Instead, I first *engaged* my students by introducing them to multiple phenomenon-driven, discrepant events (i.e. *inverted bottles*), which directed our inquiries towards *exploring* the phenomenon more purposefully (i.e. *The Great Ice Investigation*). After completing the first two "E's", we move forward to the *explain* phase of the learning cycle.

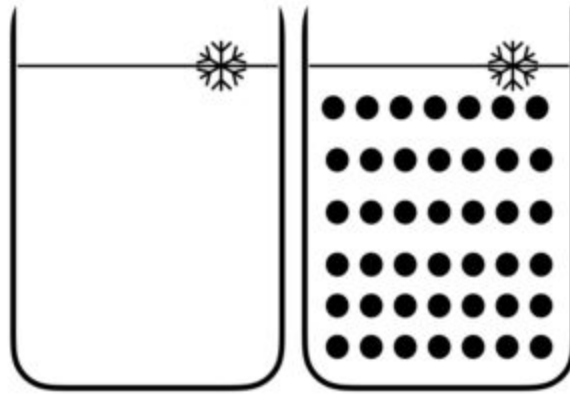
Even though my PSTs will be elementary teachers, I target a middle school *Performance Expectation* [PE] (Disciplinary Core Idea/MS-ESS2-6: *Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents.*) because they are adult learners and also because the complexity of many PEs jumps significantly in middle school. Next, I gather students around in a circle and pass out two different "density cubes" to each group. Each homogenous cube is identical in size (1" by 1"), but made up of a different material (e.g. PVC, pine, oak, steel, etc.). After allowing students time to manipulate and ask questions about their cubes, I present them with a relatively large container of water and ask them to predict which of their cubes will float (e.g. oak or steel). Students generally make accurate predictions, but when asked to connect the reasoning for their predictions to the results they just reported out from the ice investigation, most struggle. I therefore prepare one final demonstration by making a single adjustment to the original ice investigation I conducted with tap water and salt water. After again placing two ice cubes in separate beakers of tap water and salt water, I lightly drop three to four drops of food coloring on top of the ice cube in each labeled container (Figure 2). Within about 30 seconds, it quickly becomes clear that the water melting directly off of the ice cube in tap water (Figure 2 – colored blue) is moving differently than the other (Figure 2 – colored red). More specifically, the now visible, blue-dyed water melting off of the ice cube begins dropping down to the bottom of the beaker and spreading throughout the beaker. After multiple drops of ice-cold water rapidly move and spread throughout the beaker the solution soon turns entirely blue. The saltwater solution however, remains relatively clear as the cold red water melting off of the ice cube remains near the top of the beaker thereby keeping the ice cube from melting longer.

*Figure 2 (Click on image to enlarge). Visual demonstration of the ice investigation with food coloring.*



With the results of this demonstration still visible, each group is given a small white-board to draw what they are now observing in each beaker. In particular, I ask them to draw “enlarged” dots that represent the salt dissolved in one of the solutions along with colored drawings and arrows that model the NOW VISIBLE movement of water in the tap water solution. After having multiple groups share and discuss their drawings, the idea of “density” inevitably comes up. In addition to saying the “vocabulary word”, I also prompt students to reflect on what density means in relation to the multiple experiences and demonstrations we recently completed. As we discuss our ideas I add additional language and explanation around one of the group’s drawings by introducing them to the word “atoms”. I suggest water (in solid and liquid states) and salt are composed of particles too small to be seen and that these particles: (1) are in constant motion and (2) interact differently depending on certain characteristics like composition and temperature (NRC, 2012). Figure 3 displays how the saltwater solution in one of the beakers prevents the water that melts off of the ice cube from moving downward. In sum, this phenomenon occurs because the cold water melting off of the ice cube is less dense than the “tightly packed” saltwater solution, which contains far more solutes dissolved in solution. With no additional particles being dissolved in the tap water solution (Figure 3, left beaker), gravity forces the cold (more densely packed) water melting directly off of the ice cube to move to the bottom of the beaker. Next the slightly warmer water at the bottom of the beaker moves up towards the ice cube causing it to melt. I often direct students to draw arrows on their diagrams that depict this movement, or cycling, of water throughout the tap water beaker. Note: it can be helpful to provide students with the terms solute (substance being dissolved) and solvent (liquid dissolving the solute), but this is not always necessary.

*Figure 3 (Click on image to enlarge).* Sample model drawing of ice cubes melting in tap water (left) and salt water that includes enlarged salt particles dissolved in solution (right).



This initial explanation of the phenomenon is also accompanied by a “jig-saw reading” of multiple, brief articles about water density and ocean currents taken from different national organizations (c.f. <https://water.usgs.gov/edu/density.html>). During the jigsaw students discuss the contents of each article with the group after individually reading their assigned article. Contents of each of the articles further describe the role of density, salinity, and/or temperature in various contexts (e.g. climate change) with all involving the movement of water in one way or another. An optional/supplemental lesson fits in well at this point if needed. The lesson (titled: *People as Particles*; Tretter & McFadden, 2018) targets the structural properties of matter by engaging people (i.e. students) as particles (i.e. atoms) using scientific modeling as the driving scientific practice. With the end of the second class coming to a close, I tell students we will be running the final version of the ice investigation during the next class. However, during this final investigation groups must purposefully infuse their conceptual understanding of water density into the design of the investigation. For example, a student group might propose varying their procedure by modifying the location of the ice cube in the beaker (e.g. near the bottom) using a plastic piece of mesh and a weight. With the ice cube always situated at the bottom of the beaker one can then predict it will melt at relatively the same time in a saltwater and tap water solution because the movement of water (c.f. Figure 2) is no longer a factor in melting the ice cube. In the end student groups often strive to modify their procedure in creative ways at this point given their newly developed conceptual understanding of the phenomenon of interest. Overall, the variety of students’ design ideas at this point make this final round the most engaging of all.

## Between Class Readings

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I again assign readings between classes starting with the next chapter in the course-assigned book (Harlen, 2015). The chapter (titled – *HOW Should We Teach Science?*) is accompanied with a prompt and associated response again using Flipgrid. This time around I direct PSTs’ attention to the main points of the chapter with the following prompt:

Science instruction that promotes long-term, conceptual understanding: (1) aligns with one or more “views of learning” (p. 17), (2) emphasizes “big ideas” by utilizing an inquiry approach, and (3) provides appropriate “alternative ideas” when student misconceptions arise. Discuss your understanding of each “statement” (1-3). Reply to one peer’s idea.



PSTs' responses to this prompt and others like it afford them with the language needed to discuss and think about science instruction in a manner that aligns with my overall goals for the course. More specifically, it builds up a new understanding and foundation for science teaching/learning that we can then refer back to throughout the course. We often reflect back on these initial readings, discussions, and lessons from the ice investigation because we have, in a sense, moved on to more "advanced" pedagogical strategies built upon this foundation.

Finally, I include two additional readings. The first article (titled – *Shifting from Activity-mania to Inquiry*, Moscovici & Nelson, 1998) describes "activity-mania", a teaching approach many are familiar with. In brief, activity-mania involves a "collection of prepackaged, hour-long (or less), hands-on activities that are often disconnected from each other" (Moscovici & Nelson, 1998; p. 14). My PSTs often see activity-mania in the science classrooms they observe so this article helps them understand that even if science is "covered" in an elementary classroom via activity-mania that this instructional approach will not enable their students be successful science learners. The last article (titled – *DCIs, SEPs, and CCs, Oh My! Understanding the Three Dimensions of the NGSS*; Duncan & Cavera, 2015), concisely introduces PSTs to the other dimensions of NGSS (e.g. SEPs) not explicitly discussed in the DCI reading from the previous week (Krajcik, Duncan, & Rivet, 2015). Each of these final two articles will be discussed in the forthcoming class.

## Finishing the Ice Investigation

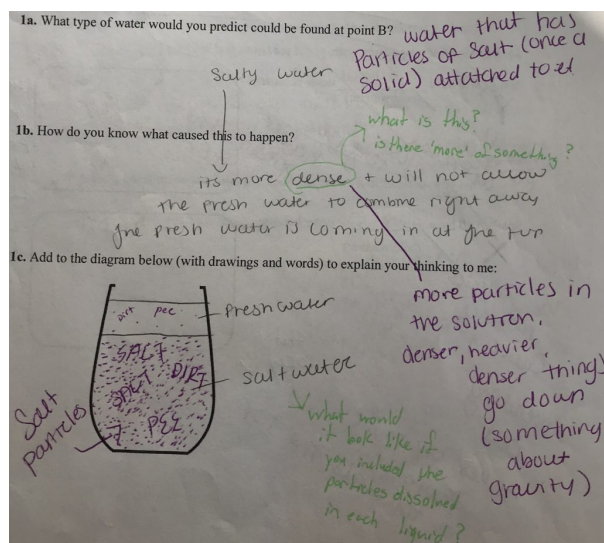
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At the start of class, PSTs quickly begin setting up their investigations. Most have brought in additional materials (e.g. chocolate/white milk) to use, which makes the class especially chaotic yet extremely stimulating, for them and myself. During the second to last "E" (*elaborate*), I feel confident my PSTs can carry out and eventually share the results of a personally meaningful inquiry. After sharing and discussing the final results of multiple group's investigations with one another, I discuss the necessary *assessment opportunity* to come up next. I tell my PSTs I created a two-dimensional assessment for learning (Heritage, 2008; Penuel, Van Horne, & Bell, 2016) in order to formatively assess their developing conceptual understanding of the concepts and ideas we have been investigating via a specific scientific practice (*conceptual idea* – density and water movement; *scientific practice* – designing an investigation). I also inform them that the classroom-embedded assessment (titled – "The River Deltas"; see *Appendix A*; adopted from Van Horne, Penuel, & Philip, 2016) is a feedback tool I will use and will return to them with written feedback, questions, and suggestions.

After finishing the assessment, and before the next class, I provide everyone with feedback on the formative assessment (e.g. "What would it look like if you included the particles dissolved in each liquid?"; Figure 4). During the next class after receiving the feedback, I provide PSTs with a purple pen and provide time for them to "purple pen" responses to the questions/comments I wrote on their River Deltas assessment. Purple penning (as a

formative assessment strategy) reiterates to my PSTs I intend to provide repeated and supported learning opportunities in order for them to be successful because they get to make a second attempt on the task. For many, this assessment experience contrasts significantly with any prior science “test” they had ever taken. We spend some time here discussing the purpose of classroom embedded assessments and the connection between assessments of this nature and our learning experiences leading up to it. More specifically, we discuss how formative assessments can be leveraged to explicitly elicit student thinking in an intentional manner so instruction can then be modified that responds to the evidence garnered.

Figure 4 (Click on image to enlarge). Sample written feedback and student response to a formative science assessment.



After this discussion I display a picture of the *inverted bottles* demonstration from two weeks ago and we discuss the cause of the observed phenomenon that previously few to none were able to make sense of. Finally, I let everyone know we will be ending the *Great Ice Investigation* and that hypothetically if we had more time we would move on to the next sequence of lessons aligned with the PE (MS-ESS2-6) we would be working towards.

## Final In-Class Readings

To wrap up the third and final class of the sequence, I engage everyone as teachers by again “jigsawing” two readings. The first (titled – *Using the 5E Model to Implement the NGSS*; Bybee, 2014; p. 63) “pulls up the curtain” on the instructional model that guided my instructional decisions during the ice investigation. Throughout the three weeks PSTs usually allude that they are wondering why I so adamantly try to teach them how density impacts the movement of water in the oceans by asking me questions about the pedagogical strategies being implemented. In brief, they want to know why I’m asking the questions I’m asking them and why I’m structuring their learning opportunities the way I am. I continually remind them that when the ice investigation comes to an end, we will break down each and every “stage” of the instructional model. By jigsawing this reading (Bybee, 2013) we start to collaboratively breakdown and discuss the multiple facets of the ice investigation. With one student each

assigned one of the five “Es”, they individually read and then discuss their respective “E” with members of the group. During their discussions, the following prompt is displayed, which each member of the group needs to respond to:

- What part of the *Great Ice Investigation* relates to your phase?
- What were you doing as students that was consistent with your phase? What was I (the teacher) doing?
- What makes your phase different from the other phases?
- What are some activities/actions that are inconsistent for teachers AND students during your phase? (Bybee, 2013; Table 3.1)

Next, and after discussing the 5Es as a whole group, we move on and each student reads one “Assumptions” from the *Framework for K-12 Science Education* (NRC, 2012). The reading contains six sections or *assumptions* (e.g. Connecting to Students’ Interests and Experiences) that PSTs can now make sense because many of the assumptions were present during the *Great Ice Investigation*. Each member of the six-student group is denoted as an “expert” to a given *assumption*, which they display describing their section of the reading to the group.

Overall these final two readings set up an invigorating whole-class discussion because my PSTs, likely for the first time, actually can see how appropriate science instruction helps students develop their conceptual understandings all the while as they engage in and learn about the process of science as a scientist would (Metz, 2008). Smaller details from the sequence of lessons, readings, and resources described here have been omitted; however, a strong instructional “skeleton” has been provided for science teacher educators to make sense of and modify according to their preferences and needs. Again, I have experienced great successes helping my PSTs understand how and why elementary science teaching/learning needs to be primarily about student sensemaking using the above sequence of lessons, readings, and resources. During our final class of the semester I redistribute the drawings they drew of their positive science learning experience (see Figure 1) along with the following prompt: *Based on where you are now, how differently would you evaluate a “positive science learning experience” compared to the start of the semester?* A representative response to this reflective prompt follows:

A positive science learning experience calls for student-lead experimentation and sensemaking opportunities. I didn’t know much about science inquiry or the practices of science before this course, but I now understand how important it is to teach my own students to question what they see and try to discover reasoning and meaning.

I believe the “lesson plans” detailed above would be of benefit to both PSTs as well as in-service elementary and middle school teachers just beginning to align their instruction with the NGSS because overall it empowers teachers to truly see how and why instructional shifts are needed in order for science instruction at the elementary level to be successful.

## Supplemental Files

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[Appendix-1.jpg](#)

[Appendix-2.jpg](#)

[Appendix-3.jpg](#)

## References

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