Towards Engagement with the Science and Engineering Practices for All Students

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ABSTRACT

The eight science and engineering practices outlined in the Next Generation Science Standards (NGSS) are key to student science learning. However, there is limited guidance for teachers on what these practices "look like" in instruction across different grade ranges and topic areas. Further, there is little existing guidance for teachers on how to make the practices in the NGSS accessible to all students, particularly those from groups that have traditionally been underserved in science education.

This paper describes the development of a primer that operationalizes the science practices for different grade levels and content areas. This work is part of a larger study aimed at developing survey items to measure teachers' use of the science practices.

INTRODUCTION

The Next Generation Science Standards (NGSS) provide a vision of science instruction in which *all* students develop scientific literacy, and promote a blending of science and engineering practices with disciplinary core ideas and crosscutting concepts (NGSS Lead States, 2013). The three dimensions are intertwined such that students learn targeted content ideas through engaging in the practices to develop explanations for real-world phenomena. The eight practices outlined in the NGSS—asking questions/defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations/designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information—are, thus, critical to students understanding science and engineering.

The NGSS draw from National Research Council (NRC) reports indicating that students from diverse backgrounds are able to successfully engage in the practices and understand science concepts when they are provided with equitable learning experiences (NRC 2007, 2008, 2011). However, research indicates that this vision of providing equitable access to quality science learning experiences is far from being realized. Data from 2012 National Survey of Science and Mathematics Education (NSSME) show that well-prepared teacher are distributed unevenly across schools with different student populations, with disparities both in the amount of experience teachers have and in their professional preparation. For example, classes with high percentages of students historically underrepresented in STEM and classes in high-poverty schools are more likely to be taught by novice teachers than their counterparts. Additionally, science teachers in high-poverty schools are less likely than those in low-poverty schools to have a science/science education degree (Smith, Trygstad, & Banilower, 2016). Given these types of unequal access to education resources, the persistent achievement gaps found in the National Assessment of Educational Progress are not surprising (National Center for Education Statistics, 2012).

Achieving the goals of the NGSS will require long-term effort and significant changes to how new teachers are prepared, professional learning opportunities for in-service teachers, instructional materials, and assessments, as well as other aspects of the science education infrastructure (National Science Teachers Association, 2013). In addition, and foundational to these efforts, guidance will be needed on what the practices "look like" when they are operationalized in instruction. As the implementation of the NGSS unfolds, it will be essential to measure NGSS implementation, and examine the extent to which students are being provided with equitable learning experiences.

This paper describes one component of a larger study aimed at developing survey items to measure student opportunity to engage in the science practices, with the ultimate goal of monitoring progress towards widespread student engagement with the science practices. Specifically, the development of a primer is describe that characterizes key elements of the science practices[1] and provides illustrative examples of how these key elements play out in instruction across different grade bands (K–2, 3–5, 6–8, 9–12) and subject areas (biological sciences, Earth sciences, physical sciences). We envision the primer providing fodder for the needed national discussion about implementing the NGSS that will require developing a common vocabulary to discuss the practices. The key elements of the practices also serve as the basis for the survey development, which ultimately will be one of several tools for monitoring student opportunity to experience high-quality science instruction.

PROCEDURE

Two methods of data collection were used to inform development of the primer. First, an extensive review of existing literature was conducted on how the practices can be incorporated into classroom instruction. Second, an online, modified-Delphi panel (Miller & Pasley, 2012) was convened to identify key aspects of instruction that students need to experience for each of the science practices at different grade bands and areas of science. These activities are described further in the following sections.

Literature Review on the Practices

A literature review was conducted to identify and summarize current research and practice-based knowledge focused on engaging students with the science and engineering practices. A search utilizing the ERIC and Google scholar databases was conducted to find articles on the NGSS practices published since the release of the *Framework for K–12 Science Education* in 2011(NRC, 2011) as we assumed that relevant work that preceded it was already incorporated in the Framework.

Key words and phrases (e.g., *science and engineering practices*, *NGSS*, *models*, *argumentation*, *explanations*) were used in conjunction, and the initial search resulted in 76 empirical and practitioner articles and conference papers. These articles were reviewed more carefully and articles that included only general descriptions of the practices were removed from the literature pool. The remaining 47 articles were coded by the practices, grade levels, and subjects addressed, when possible.

[1] Presently, project efforts are focused only on the science practices. However, it is possible that this work may expand to the engineering practices in the future.

References to all of the articles included in this literature review, coded to the practices they address, can be found in the Appendix. The majority of the articles that passed the screening were from practitioner journals (35 articles). Articles intended for high school teachers (16) were the most prevalent, followed by middle school (12), and elementary (7). Frequently these practitioner articles focused on one or two of the practices, detailing how they play out in the classroom. The remaining 12 articles were either empirical or products of conference presentations. The description of the practices culled from these articles was used as a foundation for the questions posed in the subsequent panel.

Expert Panel

An expert panel was convened to "unpack" the science practices, identifying key elements of the practices in different grade bands and areas of science. The panel was composed of individuals with backgrounds and experiences in different grade levels and content areas. In addition, panelists had varied levels of involvement with the NGSS, including some panelists who served on the writing team.

The panel process involved four rounds of questions that were emailed to the panelists. Questions in Rounds One and Two addressed four practices: constructing explanations; engaging in argument from evidence; obtaining, evaluating, and communicating information; and using mathematics and computational thinking. Rounds Three and Four focused on the remaining practices: developing and using models, asking questions, planning and carrying out investigations, and analyzing and interpreting data. Panelists were asked to complete a series of questions/tasks related to each practice including: (1) constructing a definition of the practice; (2) identifying the key elements of what students need to experience at various grade levels and in different science content areas that are essential for them to understand the practice; and (3) generating examples of what instruction "looks like" as students engage with the practice.

Constructing a Definition of the Practice

Panelists were provided with a draft definition of each science practice drawn from the Framework, NGSS, and various articles collected as part of the literature review. They were asked to review the draft, suggest revisions to the definition they deemed as necessary, and provide a rationale for any revisions they recommended (see Figure 1). The definitions provide by each panelist was used as a lens to interpret their remaining responses to questions/tasks related to that practice.

The Next Generation Science Standards (NGSS) and various articles characterize the practice of asking questions. From those sources, we have developed the following definition:

> *Asking questions is the science practice of generating queries about phenomena, systems (or parts of systems), or proposed explanations or models that can potentially be answered with explanations supported by empirical evidence.*

a. Use track changes to make any revisions to the definition that you think are necessary.

Asking questions is the science practice of generating queries about phenomena, systems (or parts of systems), or proposed explanations or models that can potentially be answered with explanations supported by empirical evidence.

b. Please provide a rationale for the revisions that you made to the definition.

Figure 1

Identifying the Key Elements of the Practice

For each science practice, panel members were asked to provide a detailed example of instruction engaging students in the practice as part of meeting an NGSS performance expectation or learning about a particular topic area. Panelists were then asked to identify the key elements of what students were doing in their description that are essential for helping students master that practice. In addition, panelists were asked to specify whether/how the key elements differed by grade band and science content area. The key elements offered by the panel, along with other key elements identified in the literature review, were compiled.

In the subsequent round, panelists were asked to provide feedback on the set of compiled key elements, noting whether they: (a) agreed that the element is essential for helping students master the practice; (b) agreed that the element is essential for helping students master the practice if modified (providing the edits needed); or (c) disagreed that the element is essential for helping students master the practice (see Figure 2). Panelists also had the opportunity to add key elements that were missing from the compiled list and to specify at which grade bands students should experience each of the listed elements.

Feedback on Key Elements of Planning and Carrying Out Investigations

For each element listed, we would like you to do three things. First, indicate whether you (a) agree that it is essential for helping students master the practice, (b) agree that it is essential for helping students master the practice *if modified*; or (c) disagree that it is essential for helping students master the practice. (If you select option b, please indicate the edits needed along with a rationale for the changes. If option c is selected, please provide a rationale.) Second, indicate at which grade bands students should experience the element. Third, describe how the level of complexity with which students should experience the element varies at different grade bands.

Key Element: Identify what evidence is required to answer a scientific question

1. Which best describes your agreement with the key element listed? (*Please select one of the three options below by either checking the box to the left or highlighting the response.*)
   a. ☐ I agree that this element is essential for helping students master the practice of planning and carrying out investigations.

   b. ☐ I agree that this element is essential for helping students master the practice of planning and carrying out investigations *if modified.*

   Please provide the edits you would suggest along with a rationale for the changes.

   c. ☐ I disagree that this element is essential for helping students master the practice of planning and carrying out investigations.

   Please provide an explanation for why you disagree.

2. At which grade band(s) should students experience this element, regardless of the complexity with which they experience it? (*Please select all that apply by either checking the boxes to the left or highlighting the responses.*)
   ☐ K–2
   ☐ 3–5
   ☐ 6–8
   ☐ 9–12

3. Describe how the complexity of this element varies at different grade bands. *(If you do not believe the complexity varies across grade bands, simply put "NA.")*

Figure 2

Generating Examples of Students Engaging with the Science Practices

Throughout the four rounds, panelists were asked to generate descriptive examples of instruction in order to operationalize what instruction would "look like" when student experience a particular practice (see Figure 3). As noted previously, panelists provided descriptive examples in order to generate a list of key elements. In addition, panelists were asked to use the final list of key elements to provide a detailed example of students engaging with a science practice in order to illustrate what the practice looks like at a particular grade band and identify differences across grade bands.

Example of Analyzing and Interpreting Data

Considering the revised list of elements for *analyzing and interpreting data* that you have specified in this round (i.e., all of the elements you have agreed with, edited, or added), please provide the following at a grade band and content area of your choice:

a. A detailed example of students *analyzing and interpreting data* that illustrates how students experience this practice at the selected grade band. Please be specific in your illustration.

b. A description of how your example illustrates the key elements of *analyzing and interpreting data.*

On what grade band does your description focus? *(Select a grade band by either checking the box to the left or highlighting the response.)*

☐ K–2
☐ 3–5
☐ 6–8
☐ 9–12

Detailed example for *analyzing and interpreting data*

Description of how example illustrates the key elements of *analyzing and interpreting data*

Figure 3

DATA ANALYSIS

Data gathered during the expert panel process were analyzed in an ongoing fashion during the data collection period. The first round of panel responses were analyzed in order to frame the second round of questions, an iterative process that continued through all rounds of the panel. Use of the three strategies (constructing a definition of the practice, identifying key elements of the practice, and generating examples of students learning science through engaging with the science practices) led to a purposeful accumulation of data and vetting of emerging themes. The goal in data analysis was to identify and verify key elements of a practice, meaning that they were ideas that panelists largely agreed were important for the practice under discussion.

In each round of the panel, responses to each question posed produced a data set that was analyzed. Project staff constructed a simple thematic coding scheme for analyzing each item in each round and tracking the strength of agreement (e.g., similar responses for an item). In addition to the reflections that panelists offered in each round of the panel, the examples that they provided were treated as data to be coded. These examples were analyzed as short narratives of particular practices in terms of the relationships illustrated or explicated.

FINDINGS

The process of reviewing the literature review on the practices, in conjunction with the expert panel process, yielded set of key elements for each science practice that operationalize what student should experience as part of engaging in a particular practices.[2] In the process of working with the panel and reviewing the literature, a number of findings emerged which have important implications for widespread implementation of the NGSS and developing instruments to measure the extent of implementation.

There is variation in how teachers, teacher educators, researchers, and other stakeholders view the nature and role of the practices.

The panel process revealed substantial differences in how people define the science practices and describe "what it looks like" for students to engage with a particular practice. For example, panelists varied on what constitutes a "model," with some agreeing that models are physical, graphical, or mathematical representations of phenomena while another noted that models can also be mental representations. There were also differences in how panelists viewed the purpose of particular practices. For example, some panelists interpreted the practice of "asking questions" as those questions that lead to an investigation. Other panelists had a broader view of questions, recognizing the practice of questioning in developing an investigation, but also recognizing the role of questioning in other science practices such as clarifying evidence or the

[2] The primer will include definitions and key elements for all of the science practices. The primer is in the final stages of development, and will be available on our website soon: www.horizon-research.com.

premise of an argument. In addition, there was an inherent tension between describing the practices alone for clarity and incorporating their descriptions with disciplinary core idea and crosscutting concepts.

Relatedly, it quickly became apparent that even among the expert panel, key terms related to the practices are used in different ways. For example, panelist varied in how they used the terms "claims," "arguments," and "explanations." As a result, it was difficult to obtain total consensus on what it "looks like" to engage with the science practices in the context of a K–12 instruction, particularly in the computational thinking.

Lack of clarity about what constitutes engaging in the practices will present a challenge to achieving high-quality implementation of the NGSS throughout the nation as teachers will likely need extensive guidance on how students should experience the NGSS practices in K–12 instruction. This issue was also apparent in cognitive interviews conducted with teachers as part of developing items to measure implementation of the practices. For example, "computational thinking" is a particularly problematic phrase. Interviewed elementary teachers often defined computational thinking as doing computation—addition, subtraction, multiplication, and division. At the secondary level, teachers described computational thinking as anything involving computers, including simply using a word processor. The experience of this project points to the need to provide clear guidance for teachers in implementing the practices in their classrooms, and resources that clearly describe how students should engage with the practices and clarify terms used in these descriptions. For this reason, the primer includes definitions of the practices with an unpacking of what students should experience as part of engaging with each practice (the key elements). In addition, it includes a glossary of important terms used in these descriptions. Our hope is that these definitions and descriptions will foster productive conversations around the practices and create a broader, consensus understanding of their role in science education.

The practices often have overlapping elements and are used concurrently in science.

Because the practices overlap as they are used in science, it was sometimes difficult for panelists to tease apart key elements for individual practices. For example, elements of using mathematics and computational thinking often occur as part of analyzing and interpreting data. Although deconstructing the practices into key elements is necessary for understanding what is involved in engaging in a practice, we recognize that it is inauthentic to consider key elements and practices in isolation, as the practices are often used in connection with each other. For this reason, the primer includes vignettes that illustrate how instruction that incorporates the key elements might appear in different subject areas and grade bands.

The ultimate goal of science is the development of evidence-based explanations for, and models of, the natural world. The science practices are in the service of these goals, and critical to students gaining an understanding of how scientific knowledge is generated.

Although the practices are intimately intertwined, the unpacking process highlighted the danger that the ultimate goal of science could get lost by focusing on individual practices. The science practices are critical to achieving this goal, as students need to understand that scientific evidence is generated through a systematic and social process. Thus, it is important that teachers keep this ultimate goal of science in mind when planning and delivering instruction so that students develop an understanding of how the practices are in service of this goal.

The science practices apply to all fields of science and grade levels.

Throughout the rounds of the expert panel, panelists consistently agreed that (a) the practices do not differ across topics/subject areas, and (b) student engagement in the practices grows progressively more complex as grade level increases. However, as the key elements of the practices were further unpacked, it became apparent that some key elements are too sophisticated for students in the lowest grade bands to engage with in authentic ways, particularly some aspects of mathematics and computational thinking. It also became evident that as students progress through the grade bands, it may become unnecessary for teachers to explicitly engage student with some of the key elements of practices since students will have sufficiently engaged with particular aspects of a practice in earlier grades. For example, assuming students have learned to distinguish scientific and non-scientific questions in previous years, high school teachers will likely not have to emphasize this aspect of asking questions.

Students need to have opportunities to reflect on their use of the practices.

In addition to having opportunities to engage in the science practices, it became apparent that students should also have periodic opportunities to engage in metacognition about their learning and be asked to explicitly reflect on their use of various practices. For example, if students use different types of models (e.g., descriptive, relational) for various purposes (e.g., to make predictions, to compare with other models) over the course of their 8th grade science class, the teacher may want to help students reflect on the various types models they have used and discuss the purpose of models more broadly in science.

DISCUSSION

The primer, developed through an extensive literature review and expert panel process, provides a much needed opportunity to further the discussion about how NGSS-aligned instruction, in particular the science practices, can be implemented in K–12 classrooms. The primer sets forth definitions of each practice, key elements of what student engagement in each practice would involve, and illustrative examples of how these key elements play out during instruction. The lessons learned in the process of creating the primer highlight the need for, and value in, the indepth discussions, informed by both the literature and practitioner knowledge, about implementing the NGSS in classrooms. They also highlight the importance of providing concrete and accessible examples NGSS-aligned instruction as objects of inquiry for these discussions. Given the historic inequities in science education, making these types of resources widely available may be an important first step in closing the equity gap.

The development of the primer also had a number of implications for development of the survey that is the ultimate goal of this study. That the panel agreed that the key elements of each practice applied to all content areas indicated that it was not necessary to develop different items for different science topics. However, the level of complexity at which students might engage with a practice would be expected to vary across grades bands, indicating that separate items might be needed for teachers at different grade levels.

A second challenge highlighted by the primer development was the wide variation in how people view the nature and role of the practices. For survey items to be valid, respondents must interpret the questions as intended. The variation in thinking about the practices that we encountered in the literature and panel process foreshadowed a number of issues we uncovered in cognitive interviews with teachers around draft survey items.

A third implication is that survey items related to metacognition around the practices would be a valuable tool for monitoring implementation of the NGSS. The panel agreed on the importance of teachers providing opportunities for students to not only engage in the practices to develop an understanding of important science ideas, but to also reflect on how the practices were enabling them to develop those understandings so that they would both better understand how scientific knowledge is generated and revised and gain facility with the diverse methods of scientific inquiry. Although we are not able to tackle this aspect of instruction in our current study, it clearly points to an area in need of further work.

References

Miller, B. & Pasley, J. (2012). What do we know and how well do we know it? Identifying practice-based insights in education. Evidence and Policy, 8(2), 193–205.

National Center for Education Statistics. (2012). The Nation's Report Card: Science 2011 (NCES 2012-465). Washington DC: U.S. Department of Education.

National Research Council. (2007). Taking science to school: Learning and teaching science in grades K-8. Washington, DC: National Academies Press.

National Research Council. (2008). Ready, set, science!: Putting research to work in K-8 science classrooms. Washington, DC: National Academies Press.

National Research Council. (2011). A framework for K-12 science education: Practices, crosscutting themes, and core ideas. Washington, DC: National Academies Press.

National Science Teachers Association. (2013). NSTA position statement: The next generation science standards. Retrieved from: http://www.nsta.org/about/positions/ngss.aspx.

Next Generation Science Standards Lead States. (2013). Next Generation Science Standards: For States, By States. Retrieved from: http://www.nextgenscience.org/

Smith, P. S., Trygstad, P. J., & Banilower, E. R. (2016). Widening the gap: Unequal distribution of resources for K–12 science instruction. *Education Policy Analysis Archives, 24*(8), 1–42.

APPENDIX

ARTICLES INCLUDED IN LITERATURE REVIEW

Bell, P., Bricker, L., Tzou, C., Lee, T., & Van Horne, K. (2012). Exploring the science framework. *Science Teacher, 79*(8), 31–36.

Berland L. K. & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching, 49*(1), 68–94.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education, 95*(4), 639–669.

Brodsky, L., & Falk, A. (2014). Scientific explanations and arguments: Building new science content knowledge through argumentation. *Science Scope, 37*(9), 12–18.

Campbell, T., Neilson, D., & Oh, P. S. (2013). Developing + using models in physics. *Science Teacher, 80*(6), 35–41.

Chen, Y. C., Park, S., & Hand, B. (2013). Constructing and critiquing arguments. *Science and Children, 50*(5), 40–45.

Chowning, J. T. & Griswold, J. (2014). Beyond "my opinion versus yours." *Science Teacher, 81*(1), 39–45.

Clary, R. & Wandersee, J. (2013). Arguing history. *Science Teacher, 80*(5), 39–43.

Covitt, B. A., Harris, C. B., & Anderson, C. W. (2013). Evaluating scientific arguments with slow thinking. *Science Scope, 37*(3), 44–52.

Cunningham, C. M., & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education, 25*(2), 197–210.

Damico, J. (2014). Can you picture that? *Science Teacher*, *81*(2), 50–55.

Dash, C. & Hug, B. (2014). Demystifying data. *Science Teacher, 81*(8), 51–56.

Falk, A., & Brodsky, L. (2013a). Incorporating models into science teaching to meet the next generation science standards. *Science Scope*, *37*(1), 61–69.

Falk, A., & Brodsky, L. (2013b). Scientific explanations and arguments: Understanding their nature through historical examples. *Science Scope, 37*(3), 10–18.

Falk, A., & Brodsky, L. (2014). Scientific explanations and arguments: Seeing and supporting explanation and argumentation in students' talk. *Science Scope, 37*(7), 66–70.

Ford, M. J. (2012). A dialogic account of sense-making in scientific argumentation and reasoning. *Cognition and Instruction, 30*(3), 207–245.

Foster, C. H., Husman, J., & Mendoza, C. (2013, June). *Engineering solar energy in the fourth grade science classroom.* Paper presented at the American Society for Engineering Education Annual Conference, Atlanta, GA.

Gotwals, A. W., & Songer, N. B. (2013). Validity evidence for learning progression-based assessment items that fuse core disciplinary ideas and science practices. *Journal of Research in Science Teaching, 50*(5), 597–626.

Gould, R., Sunbury, S., & Dussault, M. (2014). In praise of messy data. *Science Teacher, 81*(8), 31–36.

Huff, K. & Bybee, R. (2013). The practice of critical discourse in science classrooms. *Science Scope, 36*(9), 29–34.

Knight, A. & Grymonpre, K. (2013). Assessing students' arguments: How strong are their justifications? *Science Scope, 36*(9), 51–59.

Krajcik, J. & Merritt, J. (2012). Engaging students in scientific practices: What does constructing and revising models look like in the science classroom? *Science and Children, 49*(7), 10–13.

Kraus, R. (2014). Reflecting on data. *Science Teacher, 81*(8), 45–49.

Krell, M., zu Belzen, A. U., & Krüger, D. (2014). Students' levels of understanding models and modelling in biology: Global or aspect-dependent? *Research in Science Education, 44*(1), 109–132.

Lachapelle, C. P., Sargianis, K., Cunningham, C. M. (2013). Engineer it, learn it: Science and engineering practices in action. *Science and Children, 51*(3), 70–76.

Lee, E. J., Cite, S., & Hanuscin, D. (2014). Taking the "mystery" out of argumentation. *Science and Children, 52*(1), 46–52.

Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher*, 0013189X13480524.

Llewellyn, D. (2013). Making and defending scientific arguments. *Science Teacher, 80*(5), 34–38.

Llewellyn, D. & Rajesh, H. (2011). Fostering argumentation skills: Doing what real scientists do. *Science Scope,, 35*(1), 22–28.

Mayer, K., Damelin, D., & Krajcik, J. (2013). Linked in. *Science Teacher, 80*(6), 57–61.

Mayes, R., & Koballa Jr, T. R. (2012). Exploring the science framework. *Science and Children, 50*(4), 8–15.

McLaughlin, C. (2013). Engaging middle school students in the analysis and interpretation of real-world data. *Science Scope, 37*(3), 53–58.

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of Research in Science Teaching, 48*(7), 793–823.

Miele, E. & Bennett, S. (2014). Methods and strategies: Collaborating for success. *Science and Children, 51*(6), 70–76.

Milano, M. (2013). The Next Generation Science Standards and engineering for young learners: Beyond bridges and egg drops. *Science and Children*, *51*(2), 10–16.

Miller, A. R., Rivet, A., Kastens, K., Lyons, C. (2013, April). Emergence of science practices around physical models in earth science classrooms. Paper presented at the National Association for Research in Science Teaching Annual Conference, Rio Grande, Puerto Rico.

Miranda, R. J. & Hermann, R. S. (2013). Integrating science and engineering practices in an inquiry-based lesson wind-powered cars. *Science Scope, 36*(6), 54–60.

Oh, P. S. & Oh, S. J. (2013). Modeling sunspots. *Science Teacher*, *80*(6), 51–56.

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638.

Reiser, B. J., Berland, L. K., & Kenyon, L. (2012). Engaging students in the scientific practices of explanation and argumentation. *Science and Children, 49*(8), 8–13.

Rivet, A. E., & Kastens, K. A. (2012). Developing a construct-based assessment to examine students' analogical reasoning around physical models in Earth Science. *Journal of Research in Science Teaching, 49*(6), 713–743.

Sampson, V., Enderle, P., & Grooms, J. (2013). Argumentation in science education. *Science Teacher, 80*(5), 30–33.

Smith, A., Molinaro, M., Lee, A., & Guzman-Alvarez, A. (2014). Thinking with data. *Science Teacher, 81*(8), 58–63.

Sneider, C., Stephenson, C., Schafer, B., & Flick, L. (2014). Computational thinking in high school science classrooms. *Science Teacher, 81*(5), 53–59.

Taylor, L. (2013). The language of argumentation. *Science Teacher, 80*(5), 44–49.

Texley, J. (2014). Modeling what we can’t sense – Using evidence we can. *Science Scope, 37*(9), 6–9.

Windschitl, M. & Thompson, J. J. (2013). The modeling toolkit. *Science Teacher, 80*(6), 63–69.

Articles Included in Literature Review Coded to Practices

	Asking Questions	Developing & Using Models	Planning & Carrying Out Investigations	Analyzing & Interpreting Data	Using Mathematics & Computational Thinking	Constructing Explanations	Engaging in Argument from Evidence	Obtaining, Evaluating, & Communicating Information
Bell, Bricker, Tzou, Lee, & Van Horne, 2012								X
Berland & Hammer, 2012							X	
Braaten & Windschitl, 2011						X		
Brodsky & Falk, 2014							X	
Campbell, Neilson, & Oh, 2013		X						
Chen, Park, & Hand, 2013							X	
Chowning & Griswold, 2014							X	
Clary & Wandersee, 2013							X	
Covitt, Harris, & Anderson, 2013								X
Cunningham & Carlsen, 2014	X	X	X	X	X	X	X	X
Damico, 2014			X					
Dash & Hug, 2014				X				
Falk & Brodsky, 2013a		X						
Falk & Brodsky, 2013b						X	X	
Falk & Brodsky, 2014						X	X	
Ford, 2012							X	
Foster, Husman, & Mendoza, 2013		X						
Gotwals & Songer, 2013						X		
Gould, Sunbury, & Dussault, 2014				X				
Huff & Bybee, 2013							X	

	Asking Questions	Developing & Using Models	Planning & Carrying Out Investigations	Analyzing & Interpreting Data	Using Mathematics & Computational Thinking	Constructing Explanations	Engaging in Argument from Evidence	Obtaining, Evaluating, & Communicating Information
Knight & Grymonpre, 2013							X	
Krajcik & Merritt, 2012		X						
Kraus, 2014				X	X			
Krell, zu Belzen, & Krüger, 2014		X						
Lachapelle, Sargianis, & Cunningham, 2013	X	X	X	X	X	X	X	X
Lee, Cite, & Hanuscin, 2014							X	
Lee, Quinn, & Valdés, 2013		X				X	X	X
Llewellyn, 2013							X	
Llewellyn & Rajesh, 2011							X	
Mayer, Damelin, & Krajcik, 2013		X						
Mayes & Koballa, 2012	X	X	X	X	X		X	X
McLaughlin, 2013				X				
McNeill, 2011						X	X	
Miele & Bennett, 2014	X		X					X
Milano, 2013	X	X	X	X	X	X	X	X
Miller, Rivet, Kastens, & Lyons, 2013		X						
Miranda & Hermann, 2013	X	X	X	X	X			X
Oh & Oh, 2013		X						
Osborne & Patterson, 2011						X	X	
Reiser, Berland, & Kenyon, 2012						X	X	
Rivet & Kastens, 2012		X						
Sampson, Enderle, & Grooms, 2013							X	

	Asking Questions	Developing & Using Models	Planning & Carrying Out Investigations	Analyzing & Interpreting Data	Using Mathematics & Computational Thinking	Constructing Explanations	Engaging in Argument from Evidence	Obtaining, Evaluating, & Communicating Information
Smith, Molinaro, Lee, & Guzman-Alvarez, 2014				X				
Sneider, Stephenson, Schafer, & Flick, 2014					X			
Taylor, 2013							X	
Texley, 2014		X						
Windschitl & Thompson, 2013		X						
Total	**7**	**17**	**8**	**10**	**8**	**11**	**23**	**10**