USING SCIENTIFIC MODELS TO SUPPORT ELEMENTARY SCIENCE TEACHING & LEARNING ABOUT WATER

By

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A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Educational Studies

(Teaching, Curriculum, & Learning)

Under the Supervision of Professors Cory T. Forbes and Lawrence C. Scharmann

Lincoln, Nebraska

April, 2018

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University of Nebraska, 2018

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Elementary science learning contexts should engage with science as a process, acknowledging the abilities of young students to think and develop knowledge around complex phenomena (NRC, 2007). Moving towards that goal, the NGSS (2013) has identified modeling as an authentic science practice that supports students reasoning around intricate systems, highlighting processes and relationships, eliciting questions, and generating scientific explanations. The purpose of this research is to explore and identify how different populations of stakeholders engage with scientific modeling within elementary learning contexts. Additionally, hydrological phenomena are used as a platform for each of these studies due to the emphasis on water across elementary science and the extensive experiences elementary students have with water. First, 3rd and 5th-grade students' uses of model-based explanations were investigated, examining their reasoning about scientifically modeling the water cycle. Finding from this study suggest different grades responded to specific types of modeling support. Next, longitudinal work with inservice teachers connected their conceptions about modeling water to their classroom practice. Findings claim that teachers' conceptually prioritize some facets of modeling over others and changes to classroom practice were in response to students' challenges. Finally, preservice teachers' water lesson plans were examined, investigating their use of technology to model water. The culmination of these studies highlights the

need for additional support around elementary students' modeling, particularly focused on epistemological ideas. Additionally, this work highlights challenges and strengths of elementary teachers and preservice teachers' attempting to support students' scientific modeling. Findings from these studies inform the development of elementary science learning environments which incorporate scientific modeling.

DEDICATION

For My Parents

Who have always loved and supported me.

For Ashby

Who reminded me through action:
Sometimes, attaining the impossible is simply a matter of continuously putting one foot in front of the other, no matter what.
- *Drew Hayes*

ACKNOWLEDGEMENTS

I have so many people to thank but first and foremost should be my adviser, my mentor, and fearless leader, Cory Forbes. All I have done and will ever do academically is in large part due to your support and guidance. You have provided me more priceless experiences and opportunities than a person has a right to, and I will forever be grateful and indebted to your generosity of time, resources, and patience. Thank you for standing by me when others might not, for being trustworthy, helpful, loyal, and kind, for being my adviser and so much more.

Next, I would like to thank my dissertation committee, Lawrence Scharmann, Guy Trainin, & Christine Cutucache. Each of you has supported me to be better than I am and reach further than I thought possible. Thank you for writing letters, giving me pep talks, and helping guide my work forward. I promise your trust and investment in me is well placed. Other faculty who have significantly supported my endeavors include Julie Thomas, Eva Bachman, Justin Olmanson, Sean Trundle, & Christina Schwarz. Your support, emotionally and intellectually, will continue helping me orient to the world.

There have been so many teachers and many more students who I have had the privilege of working with and for. This research would not have been possible without your fortitude and flexibility. Multiple institutions including the Illinois State University, The University of Iowa, and The University of Nebraska, have provided me space, time, and mentors. Additionally, thank you to the Herbert Brownell Fellowship, the Paul and Edith Babson Fellowship, and Newman Dissertation Travel Award, for providing financial support for my research.

There are also many graduate students, some now faculty, I should thank. This process is long, and only with you was this journey achieved. Thank you to Mandy Biggers, Laura Zangori, & Jaime Sabel. Mandy, thank you for showing that of empathy love have a place in academia. Laura, thank you for supporting my writing, my thinking, and my whimsical schemes. From modeling to steampunk, your insights and thoughts were fundamental to my growth. Jaime, thank you for being with me through so much of this crazy adventure. No one will understand the way you do; you are my academic touchstone, a voice of sanity and stability when all else is lost. Having shared many of my challenges and triumphs, I am grateful beyond measure. To the three of you, thank you. I could not have asked for better academic big sisters. To Kari Nelson, Diane Lally, and Florian Böschl, thank you. Kari, your tenacity and drive was awe-inspiring, despite all challenges you conquered. You brought perspective and calm during a tumultuous time. Diane, thank you for your support and encouragement. I promise to 'just keep swimming,' but please know there were days I could not have done so without you. Flo, thank you for helping me think more deeply about modeling and participating in all my shenanigans along the way. From lab coats to cookie dough, Felix Felicis could not have done better in bringing us together.

Finally, I need to thank my family and friends. My parents, Thong Vo & Huong Vo, who have supported, loved and encouraged me. You taught me to value education and family. I promise to make you proud. Thank you, Nghi Vo, for checking in with me day and night. To my friends, Margaret, Josh, Farah, Richard, Angelica, Dagen, Kelsey, Ashley, Bev, Katie, Liam, Sila, Sophia, and Jessica. You were and are the best support network I could have ever asked for. I promise to pay it forward.

To the love of my life, Ashby Mullin-Conant. Thank you for fighting every battle with me. For picking me up every time I faltered. For sitting with me when I was sick, for laughing with me when I was silly. For making our house a home and reminding me there is so much to this world outside of my papers and books. There is no one else in the world I would want by my side. Thank you. Such grand adventures await us.

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CHAPTER 1

Introduction

Science education reform efforts within the last decade have served as a call to action for the science education community, asking for more research and evidence focused on supporting students' understandings of the natural world and promoting science literacy through inquiry-based science education. Many of the programs, curricula, and educational interventions designed to advance this agenda have been structured around authentic science practice. One reform document that has framed essential science practices for students has been the Next Generation Science Standards (NGSS Lead States, 2013). NGSS emphasizes that scientific practices reflect how scientists engage with the world when developing new knowledge. Further this document (NGSS, 2013) argues that students should similarly engage in scientific practices to develop a robust understanding of science (i.e., science literacy). Furthermore, this document, which has been adopted in 18 states and has influenced more than half of states' science reform documents, calls for scientific practices to be a core component across the K-12 continuum, including elementary (K-5) contexts. This rational, while not novel, is derived from progressions-based sociocultural constructionist ideas, postulating that a solid foundation of science experiences for elementary students that mirror authentic science communities would allow for complex sense-making as students progress through their education (Duschl, 2008).

Unfortunately, the current state of elementary science does not reflect a strong focus on these science education reform goals. With more than 40% of elementary schools reporting science engagement occurring 2-3 times weekly for less than 30

minutes per session (compared to 99% of elementary schools engaging in math daily for ~ 60 mins) (Banilower et al. 2013), more work appears necessary to support early learners' science learning as defined in NGSS.

One area in need of investigation and support for early learners is earth science, identified by the NGSS (2013) as a critical foundation for elementary students learning about science. An international report on students' math and science trends (Stephens et al., 2016), found that when American elementary students engage with science activities regularly, at least 80% of students were exposed to earth science materials. This indicates that the majority of the limited time elementary students engage with science occurs around geosphere processes. Elements of earth science, such as the investigation of hydrological phenomena and how they are connected (e.g., the water cycle or earth water interactions), provide a unique venue for primary student investigation, as the students have personal and prior experiences with water to negotiate with classroom experiments. Hydrology provides a complex and robust platform for students to begin developing scientific skills. However, the complexity of this disciplinary core idea can be time-consuming to investigate with young students. Elementary contexts face many unique challenges in addition to limited instructional time. This includes (a) a focus on fun/motivation instead of content (b) limited connection between activities (c) limited opportunities for sense-making and "wrapping up" (d) lack of instructional resources and scientific tools (e) reliance on externally published curriculum materials, both commercial and-noncommercial (NASEM, 2015). Each of these challenges can be seen when teaching students about water's interaction with humans and earth materials.

Study Rationale

One science practice that can support and mediate many of these challenges at the primary level is scientific modeling, a core scientific practice identified in NGSS (2013). As an approximation of the real world, scientific models are tools scientist use to negotiate differing understandings of natural phenomena. In the past few decades, there has been an increased interest in educational reform to integrate scientific modeling into more traditional science curriculum (AAAS 1993; NRC, 1996; NRC, 2007; NRC, 2013). In part, this is due to a contemporary shift in thinking about science as multidimensional, including a process of engagement and inquiry along with the customary development of new content (Barrow, 2006; DeBoer, 2000; NRC, 2013). While scientific models can and should be used to support students' reasoning about and development of content knowledge, there are additional benefits to their use. Models as both a scientific tool and a practice of science contextualize how science is developed and performed within and across science content. Elementary students' use of models to reason about natural phenomena, including their epistemic, practice-based, and conceptual dimensions, is the crux of my research.

In the nearly two decades between the National Science Education Standards (NRC, 1996) and the Next Generation Science Standards (2013), many core components science education remained steadfast, perhaps most markedly a focus on inquiry. Many of the approaches to inquiry-based science also remained intact, including developing students' curiosity, supporting their capacity for explanation, and using evidence. While other elements of inquiry-based science education have been probed within primary settings, including students' use of questions (Eslinger, White, Frederiksen, & Brobst,

2008; Forbes & Davis, 2010), negotiating arguments (Berland & Riser, 2009; Cavagnetto, 2010), and interpreting data (Barab et al., 2000; Lin, Hsu, & Yeh, 2011), scientific modeling was a pioneering addition to the national standards, particularly within elementary contexts. The incorporation of scientific modeling represents another step toward elementary students' science literacy, asking students and teachers to know not only science concepts, but also the procedures, practices, and social norms that allow science to advance. By creating and adhering to these standards, we need to support students' robust conceptual understandings, enabling them to connect and change their ideas as the data dictates, much like a scientific model. For example, there is strong documentation around student's alternative conceptions about hydrological phenomena (Ben-zvi-Assarf & Orion, 2005; Dickerson & Dawkins, 2004; Forbes, Zangori, & Schwarz, 2015; Gunckel, Covitt, Salinas, Anderson, 2012; Hmelo-Silver & Pfeffer, 2003; Schwarz, 2009 Zangori, Forbes, & Schwarz, 2009), many of which revolve around hard-to-see facets of the water cycle (e.g., evaporation, groundwater) or hidden mechanisms which cause the movement of water (e.g., gravity, temperature). As a scientific tool, models can direct attention to critical components of hydrological phenomena and support students in making other elements more visible. This helps students to recognize the integrated relationships among hydrological phenomena and garner experience using a scientific tool. Additionally, elementary students' engagement in science modeling lays the foundational pieces in their scientific, educational progression and indicates how they will continue to engage with science across different content areas throughout their formal educational career. Therefore, further research is warranted.

This inclusion of scientific modeling as an important science practice was due, in part, to research indicating that implementation of scientific models in teaching has been empirically successful, helping students garner a better understanding of specific content (Annetta, Minogue, Holms, & Cheng 2009; Etkina, Warren, Gentile; 2006; Halloun, 1996; Shepardson, Wee, Priddy, & Harbor, 2007; Wells, Hestenes, Swackhamer, 1995). However, this fruitful student engagement is impacted by teachers' knowledge of content and commitment to providing opportunities for students to engage in modeling that content (Akerson et al., 2009; Windschitle, Thompson & Braaten, 2008) in authentic ways. Because of the recent inclusion of scientific modeling within educational science standards, teachers also have a dearth of experience with modeling, both as student and teacher. Because there is an expectation teachers will provide for students opportunities to engage in this science practice, it is imperative to investigate student's engagement, teachers' practice, and how we prepare teachers to scientifically model. Given the numerous challenges that elementary educators and students already face when endeavoring to engage with science, it is important to investigate and explore how scientific modeling materializes within elementary contexts for different elementary stakeholders.

Theoretical Framework

Before moving forward to explore how scientific modeling is being used in multiple elementary contexts, it is important to explain the theoretical underpinnings that guide my work because of the ramifications they have on instructional practice and the design of educational environments. To that end, I will first discuss situated learning theory and how that framework impacts students' learning of science processes and

content. Second, I will discuss how scientific modeling aligns with and builds upon that theory, before finally explaining how these ideas feed into my conceptual framework. My study leverages situated learning theory to guide and align multiple working pieces through my conceptual frame. This theory is particularly appropriate when dealing with science education due to the field's shift towards more authentic inquiry and supporting students' construction of knowledge. To better explore situated learning theory and how it can be applied to teaching and learning science, I will use the current literature to define four major tenets of situated learning theory and link how those components are accounted for in science education to describe the construction of knowledge.

Situated Learning Theory

The roots of situated learning theory developed in cultural anthropology (DeBoer, 2000; Lave & Wegner, 1991), but when this theory transitioned to into educational circles, various aspects were ascribed as "central tenets" (Anderson, Reder, & Simon, 1997; Cobb & Bowers, 1999; Greeno, 1997). At the core of this theory is the claim that as a participant actively engages with an environment and community, the context of what they interact with inherently plays a critical role in the development of the participant's knowledge (Cobb & Bowers, 1999; Lave & Wegner, 1991; Sadler, 2009). In line with constructivism, learners still construct knowledge through interaction with and interpretation of stimuli. However, situated learning theory extends constructivist notions by insisting those interpretations are impacted by learner-centered contexts (Brown, Collins, & Duguid, 1989). Simply put, this theory claims that learning context (environment and community) plays a significant role in shaping students' interpretations.

AAAS project 2061 (2001) brings relevance to this topic in science education by placing importance on science literacy. Fostering science literacy is socially complex because the context and culture of an individuals must negotiate meaning within the culture of science (AAAS project 2061, 2001). Another major voice and stakeholder in science education, the National Research Council (NRC), has repeatedly stressed the need for more authentic and societally-related science education practices, particularly for students from diverse backgrounds (NRC, 2007; 2008; 2009; & 2012). Situated learning theory provides a path to engage students in science content and practice. It promotes science learning while simultaneously respecting and acknowledging an individual's context and culture concurrent to the culture and context of science.

To explore this further, I examine some prevalent theoretical underpinnings from the founders and developers of situated learning theory (Brown, Collins, Duguid, 1989; Cobb & Bowers, 1999; Lave, 1991; Lave & Wenger 1991), including the learner, the context, the content, and communities of practice. Then I will situate those tenets within science learning and educational research.

The learner. The learners within situated learning theory are any people willing to engage in the acquisition of knowledge through interaction. The learner brings with them pre-existing knowledge, an undefined skill set, and experiences that must be linked to the topic or subject to be learned (Choi & Hannafin, 1995). These facets feed into their development of knowledge and help situate their identity as they interact with the world around them.

The bodies of literature exploring learners' identities within science education and science classrooms include studies focused on students' attitudes, approaches towards

science, and identities within science situations. The first encompasses student efficacy, and the latter two focuses on students' personal contextual engagement. While these bodies of literature are distinct, they all discuss different views of identity defined by Gee (2001). The most prevalent view of identity within science education research seems to be the discursive identity (D-identity), situated both explicitly and implicitly throughout studies as a negotiation of identity between an individual, their peers, and their context. According to Gee (2001), the discursive perspective (D-identity) (p. 103) focuses on the negotiated identity that is developed by interacting with others, and is defined by how "people treat, talk about and interact with" (p. 103) someone. This view of a person's identity can be actively sought or passively obtained. Discursive identity within science education could be considered as individual students viewing themselves as scientist, discussing and arguing like members of a science community. Some research argues that successful performances of discursive identities (through negotiation and argumentation) are a way to access science ideas and should be considered a major indicator of science literacy (Bricker & Bell, 2008; Brown, 2004; Duschl & Osborn, 2002; McNeill & Krajcik, 2009; Sadler & Folwer, 2006).

The context. Students bring context with them from prior experiences and previously developed schema. Teachers' contexts are similar and include institutionalized norms from the school. Even the curriculum can include noteworthy contexts derived from what developers deem important. This learning theory posits knowledge is best developed by students through engagement in a rich and authentic context because the complexity within that context promotes meaningful links between and among the disciplinary knowledge gained and the skills developed (Cobb & Bowers, 1999; Lave,

1991; Lave & Wenger, 1991; Choi & Hannafin, 1995). To better understand this, I will narrow the field to discuss educational learning contexts in particular.

Situated learning theory calls for the building and linking of the knowledge students have to what needs to be learned within a particular context; therefore, the more robust and authentic the context, the greater the opportunity for learning. Many of the ideas that are foregrounded, such as the elements needed to create authentic learning opportunities within situated learning, indicate tacit learning through social context is as important as explicit learning objectives. Scholars have called for a larger investment of resources to allow teachers and students to engage in "the broader social contexts of teaching" (Kennedy, 2005, p. 197; Lortie, 1975).

Research has indicated that when science is taught within elementary contexts, it occurs sporadically and is often a series of unrelated activities (NRC, 2007; Roth et al., 2006). At the same time, researchers and experts in the field of science education have often commented on the need for educational science contexts to mirror actual science, regardless of grade level (DeBoer, 2000; NRC, 2007,2012; NGSS Lead States, 2014; Sadler, 2007). This is an idea that holds in line with situated learning theory's tenet of authenticity. The NGSS addresses the need for more authentic science contexts by introducing standards around "Three-Dimensional Learning" that highlight situational intent within science by explicitly defining the skills scientists use to solve problems and linking crosscutting concepts within the content.

The content. There are major negative cognitive implications when learning focuses on either memorizing domain-specific facts or engaging in de-contextualized domain-general processes. Therefore, the best course of action when engaging in learning

content and skills is an amalgam of the two (McNeill & Krajcik, 2009; Stevens, Wineburg, Rupert, & Bell, 2005). Situated learning theory stresses “the use of diverse concrete instances in authentic contexts. In this way, knowledge and skill become both specific and general” (Choi & Hannafin, 1995, p. 59). In concurrence with constructivist view, situated learning highlights the act of mental and physical engagement as an essential element of learning. It stretches the view by implying the need for cognitive apprenticeships with experts, still leaning on Vygotsky's ideas of ZDP while at the same time requiring that the “expert other” overtly discuss their thinking process in connection with the actions taken to improve the actions of the novice. This apprenticeship entails specific discussions around how and why actions are taken and reasoning is structured.

The NGSS (2013) practice of scientific modeling has been shown to ground and contextualize science experiments within larger scientific phenomena. In practice, elementary students’ ability to use models can help explicitly link different experiences (Zangori, Forbes, & Schwarz, 2015). These standards also align with situated learning theory’s requirement for cognitive apprenticeships, emphasizing that teachers need to discuss how and why science is done in specific ways, rather than simply having students engage in the activity. For example, students should know why it is important to identify variables, not just how to identify them.

Communities of practice. A foundational piece of situated learning theory is how communities of practice play a major part in defining the contexts and content that with which learners engage (Lave & Wenger, 1991). To better understand the role of communities of practice and how they impact learners, it is important to deconstruct the concept. Core tenants of communities of practice include *participation, identity*

construction, and continual engagement or practice. *Participation* in a community of practice is an active process, but includes more than a simple activity. It must also include facets of connection where learners situate their actions within the activity to the knowledge they currently possess, while at the same time negotiating new understandings (Handley, Sturdy, Fincham, & Clark, 2006). *Identity* should be developed within a community or practice, and it is the job of the learner to situate that new identity aspect within other currently held identities. Finally, when thinking about *continual engagement*, (Handley et al., 2006; Lave & Wegner 1991) extended engagement and exposure to a community of practice allows learners to pick up more tacit understandings within the community, becoming aware of community norms through social interactions and observations. It is through practice that a learner's identity is shaped and their participation becomes more authentic.

There has been much discussion in science education about participating in science activities vs. "doing science” across K-12 education. Educators are looking to science practices to help promote that goal (NRC, 2007; NRC, 2013; Coll & Lajium, 2011) while ultimately hoping that the classroom community takes on aspects of the scientific community. Research around the science practices of “argumentation” and “science modeling” are relevant examples of how authenticity is developed through engagement with a community. Argumentation research highlights how students engage with claims and evidence while looking at how closely students mirror language and actions of scientists (Berland & Riser, 2009) or how classroom discussion around science should be used to detail the social practices of the scientist. This contextualizes the act of argumentation as a process to be taught along with the relevant content. Some

educational modeling research has focused on how students should mimic the scientific construction of models, reasoning scientifically about critical components to include or represent content as scientists do (Baek, Schwarz, Chen, Hokayem, & Zhan, 2011). As students participate in classroom environments that are reflective of science communities, they develop tacit knowledge about the process of science along with the content. However, classroom communities centered on science are different from scientific communities, and as mentioned earlier, it is important for teachers who act as mentors within these classroom communities to provide opportunities for students to discover the differences and to explicitly acknowledge incongruities.

While situated learning defines many of the theoretical underpinnings of my study, it is mediated by the importance of model-based inquiry. These frameworks are synergistic, as model-based inquiry allows for a more focused lens of my research, identifying application specific to my research contexts. This combination eventually allows me to develop my conceptual framework. Because theories of modeling influence my studies, it is important to first define scientific modeling and explore the practice and epistemological underpinnings. Second, I will identify and unpack the specific pieces I intend on using within my study, and finally, I will explain how I used both situated learning and scientific modeling to derive my conceptual frame.

Scientific Models and Modeling in Science Education

Model-based inquiry aligns with many concepts presented in traditional science teaching associated with the scientific method, including question generation, testing and observation, revisions, and analysis. Additionally, it moves further to include the epistemic reasoning behind science (Berland et al., 2015; Schwarz et al., 2009;

Windschitl, Thompson, & Braaten, 2008). By including epistemic dimensions of modeling, the processes of "being a scientist" is revealed, which can increase students' engagement with science (Archer et al., 2010). With NGSS (2013) guidelines of 3rd -5th-grade students emphasizing the inclusion of models to develop elementary students' scientific understanding, it is important to identify significant features of model-based inquiry. Elementary contexts should "foster children's curiosity, and enjoyment in exploring the world around them and lay the foundation for a progression of science learning in K-12 settings and throughout their entire lives" (NSTA, 2014) and modeling can be a tool that helps in this endeavor. Furthermore, as it situates students' learning in an authentic practice of science. By having the learner engage with the context, practice, and tools of scientific modeling while using content (e.g., the water cycle) within a community they are able to fosters inquiry.

Scientific modeling features. Before delving further into examining literature focused on using scientific models to investigate and develop knowledge around science content, it is important to outline the construct of scientific modeling I will be referencing throughout this paper as well as define its component parts. Scientific models act as a connection between theory and "real world" experiences. They help scientists and students produce, disseminate, and justify science and serve as a simplification of scientific phenomena, making abstract ideas visible (Gilbert, Boulter, & Rutherford, 1998; Halloun, 2007; Schwarz et al., 2009). When scientific models are used to teach, engagement can occur around modeling practices (Fretz, Wu, Zhang, Davise, & Krajacik, 2002; Nersessian, 1999; Schwarz, 2009) and/or epistemic considerations (Berland, 2016; Schwarz et al., 2009; Duschl, 2008). Modeling practices show how students engage in