# Supporting Students' Construction of Scientific Explanation through Generic versus Context-Specific Written Scaffolds

Katherine L. McNeill and Joseph Krajcik
University of Michigan

contact info:

Center for Highly Interactive Classrooms, Curricula & Computing in Education

610 E. University Ave., Ann Arbor, MI, 48109-1259

734-647-4226

kmcneill@umich.edu

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**Abstract**

A student's success at performing a scientific inquiry practice requires both domain specific knowledge and knowledge of the general practice. In this study, we investigated whether providing students with written curricular scaffolds that focus on the content and task (context-specific) or on the practice of constructing a scientific explanation (generic) better supported middle school student in writing scientific explanation where they justified their claims with appropriate evidence and reasoning. To address this research question, we collected data with six teachers and 578 middle school students during the 2004-2005 school year. All six teachers enacted an 8-week standards-based chemistry curriculum, *How can I make new stuff from old stuff?*, designed to support 7th grade students in their understanding of chemistry content and scientific inquiry practices. We created two versions of the curriculum, one with context-specific scaffolds and one with generic explanation scaffolds. We then randomly assigned classes of students to either the context-specific or generic treatments so that each teacher taught both groups. Our analyses of students' pre and posttests showed significant improvement in students' written explanations over the unit for their claims and their ability to justify their claims with evidence and reasoning. In terms of the curricular scaffolds, we found that the context-specific scaffolds resulted in greater student improvement of their scientific explanations, but also in terms of their understanding of their science content. This finding raised questions about what type of knowledge the curricular scaffolds supported students in learning.

# Supporting Students' Construction of Scientific Explanation through Generic versus Context-Specific Written Scaffolds

Current research in science education calls for science instruction to move beyond teaching science as a body of facts to be memorized, rather to teach science as a way of knowing and thinking (Driver, Newton, & Osborne, 2000). Scientific literacy is conceptualized as a discourse with its own ways of talking, reasoning, and acting (Rosebery, Warren, & Conant, 1992). Specifically, recent science education standards documents (American Association for the Advancement of Science, 1993; National Research Council, 1996) advocate this view through their focus on scientific inquiry. The National Research Council's *National Science Education Standards* (1996) and companion inquiry document (2000) describe inquiry as when "…students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others…In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills" (1996, p. 2). This image of inquiry moves beyond students memorizing discrete facts to having students use conceptual knowledge in a wide variety of scientific inquiry practices.

Our work focuses on supporting students in one particular inquiry practice, scientific explanation. Our goal is to help students construct scientific explanations about phenomena where they justify their claims using appropriate evidence and scientific principles. Previous work in this area stresses the importance of helping students engage in this practice (Driver, Netwon, & Osborne, 2000; Duschl & Osborne, 2002), but also that justifying claims does not come easily to students (McNeill & Krajcik, in press; Sadler, 2004; Sandoval & Millwood, 2005). One way to help learners engage in more advanced thinking is through the use of scaffolds or supporting structures provided by people or tools (Bransford et al., 2000). In this study, we investigate whether providing students with written curricular scaffolds that focus on the content and task (context-specific) or on the practice of constructing a scientific explanation (generic) better support middle school student in writing scientific explanation during an eight week project-based chemistry unit.

## Conceptual Framework

In this section, we begin by discussing why it is important to engage students in scientific explanation. Next we discuss our instructional model for scientific explanation that we developed with our colleagues to support middle school students in scientific explanation. Finally, we introduce the question of whether context specific or generic written curricular scaffolds may provide greater support for student learning of scientific explanation.

### *The Importance of Scientific Explanation*

In our work on scientific explanation, we draw on both explanation and argumentation literature. An explanation is how or why something happens (Chinn & Brown, 2000). Specifically, scientists explain phenomena by determining how or why they occur and the conditions and consequences of the observed event (Nagel, 1961). Argumentation is a verbal (written or oral) and social activity aimed at justifying or defending a standpoint for an audience (van Eemeren, et al., 1996). In our work, we combine the goals of both explanation and argumentation in one practice we call scientific explanation. As I mentioned previously we want to support students in justifying their explanations of scientific phenomena where they support their claims with appropriate evidence and reasoning. We chose to call this inquiry practice scientific “explanation” to align with national and state science standards that the teachers we work with need to address.

Explanation (Nagel, 1961) and argumentation (Driver, Newton, & Osborne, 2000) are often discussed as core practices of scientists. Consequently, if we want students to engage in authentic science learning, these practices need to be a part of their experience. By *authentic* in this situation, I mean similar to John Brown and his colleagues (1989) who defined *authentic* practice as the ordinary practice of practitioner culture, which is often quite different than classroom culture. In terms of science education, this means that students should engage in practices that allow them to think and act like scientists. For example, Erduran and her colleagues (2004) argue that science is not about discovering or memorizing facts; rather it is about constructing explanations about phenomena. This type of explanation construction occurs within a community of scientists where different explanations are compared and debated. Scientific knowledge is far more complex, tenuous and situated in the scientific community then often recognized (McGinn & Roth, 1999). The construction of scientific knowledge is a collective and social process that occurs through conflict and argument, not simple agreement (Latour, 1987). Scientific knowledge is not truth, but a model that the current scientific community agrees upon to explain the occurrences of natural phenomena (T. Kuhn, 1970). Consequently, explanation and argumentation are core features of authentic scientific practice where scientists justify to each other their explanations for how and why phenomena occur.

Besides the idea that students should engage in explanation and argumentation, because it is an authentic scientific practice, a number of education researchers have found that engaging students in explanation and argumentation has multiple benefits for student learning as well. For example, engaging students in scientific explanation can increase students’ ability to reason and justify their claims, increase their understanding of the content, and possibly alter their view of science.

One of the goals of having students engage in explanation and argumentation during classroom instruction is to increase their ability to perform this scientific inquiry practice. The goal is to help students be able to justify their claims. A number of studies have found that when students engage in this scientific inquiry practice, their ability to construct explanations or arguments increases. For example, in previous work I conducted with my colleagues (McNeill et al., 2006), we found that engaging students in an eight week unit where scientific explanation was an explicit goal and scaffolded through written curricular scaffolds resulted in students increased performance in their ability to justify their claims with appropriate evidence and reasoning in written explanations. Schwarz and his colleagues (2003) found that when fifth grade students engaged in argumentative activities supported by technology tools that the quality of their arguments increased over the 20 hours of instruction where students provided increasingly more relevant reasons for their claims. Yerrick (2000) studied high school students in a general science class where classroom norms for instruction focused on argumentation and open inquiry. He found that after 20 weeks of instruction students’ arguments more explicitly linked their evidence to their claims and included a theoretical framework incorporating subject matter knowledge to select their evidence and justify their claims.

Besides increasing students’ ability to engage in these inquiry practices in classroom science, there is also the hope that this type of instruction would increase students’ ability to reason in science outside of the classroom. For example, Ann Brown and her colleagues (1993) suggest that *authentic* practice should foster the kinds of thinking important for out of school activities to prepare students to be lifelong intentional learners. Zohar and Nemet (2002) examined whether engagement in a genetics unit focused on argumentation would encourage 9th grade students to transfer the argumentation skills taught to the context of dilemmas taken from everyday life. Specifically, before and after the genetics unit they provided students with a dilemma around a student cheating on a test in school. They found that students were able to transfer their argumentation skills from the genetics unit resulting in students constructing stronger arguments around the everyday dilemma after the unit compared to before. Although this study suggests that argumentation skills can be transferred to other contexts, few studies have been conducted on transfer. More research needs to occur to understand whether and how students transfer their understanding of scientific explanation and argumentation from science class to other contexts both inside and outside of school.

In terms of students' conceptual knowledge, there have been a number of studies that show that when students engage in classroom instruction where explanation or argumentation is an explicit goal, they also increase their understanding of the content. For example, Bell and Linn (2000) found that when middle school students engaged in argumentation using the SenseMaker software in a debate around light propagation that students' conceptual understanding around light (such as reflection, absorption and energy conversation) increased. In my work with my colleagues, we have also found that students' conceptual knowledge of key chemistry concepts increases as well as their ability to construct scientific explanations during an eight week unit where a key focus of instruction is writing scientific explanations (McNeill & Krajcik, in press). In Zohar and Nemet's work, (2002) they conducted a comparison study to examine whether 9th grade students developed a stronger conceptual understanding of genetic ideas when they were engaged in curriculum that focused on scientific argumentation and moral dilemmas or a more traditional genetics unit, which lasted the same amount of time. They found that the genetics unit focused on argumentation resulted in greater student conceptual understanding. They provide a variety of possible reasons for this outcome including that the argumentation unit encouraged higher-order cognitive experiences that enabled students to build richer mental representations, was more interesting to students so they were more highly motivated to learn the content, and encouraged a variety of different activity structures that were not teacher centered, but rather encouraged the social construction of knowledge. These studies suggest that instructional units focused on explanation and argumentation can promote students' understanding of conceptual knowledge, perhaps better than more traditional units.

Scientific explanations frame the goal of inquiry as understanding natural phenomena and articulating and convincing others of that understanding (Sandoval & Reiser, 2004). This highlights the idea that scientists socially construct knowledge in science. Students often view science as a static set of facts or truths that scientists have collected over time by doing experiments (Songer & Linn, 1991). This is detrimental both in terms of students' understanding of the nature of science, but also because students with more dynamic views about science may acquire more integrated conceptual understandings (Songer & Linn, 1991). Having students take part in explanation construction, where they socially construct and justify knowledge claims may change or refine students image of science (Bell & Linn, 2000). Smith and her colleagues (2000) found that 6th graders in a constructivist and inquiry oriented classroom had fairly sophisticated views about how knowledge is constructed in science. Yet Sandoval and Morrison (2003) found that high school students' view of science did not change after a four week explanation-driven inquiry unit. This suggests that just engaging in inquiry or explanation might not be enough.

Rather the curriculum materials, teacher and other supports may be critical in whether and how engaging in explanation changes students' views of the nature of science.

***Instructional Model for Scientific Explanation***

In order to support teachers and students in this complex practice of constructing scientific explanations, we have developed an instructional model for scientific explanation. Similar to other science educators (Bell & Linn, 2000; Driver, et al., 2000; Erduran, Simon & Osborne, 2004; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Lee & Songer, 2004; Sandoval, 2003; Zembal-Saul, et al., 2002), our instructional model builds off of Toulmin's (1958) model of argumentation. The instructional model breaks down explanation into three components: a claim, evidence, and reasoning. The *claim* is an assertion or conclusion that answers the original question. The *evidence* is scientific data that supports the claim. These data can come from an investigation or from another source, such as observations, reading material, or archived data. The data need to be both appropriate and sufficient to support the claim. By appropriate, we mean data that is relevant to the problem and helps determine and support the claim. Sufficient refers to providing enough data to convince another individual of the claim. Often providing sufficient evidence requires using multiple pieces of data. The *reasoning* is a justification that shows why the data count as evidence to support the claim. In the reasoning component, we encourage students to articulate the logic behind why they believe the evidence supports the claim. Students may need to back up that link between the claim and evidence by including the appropriate scientific principles. In other work, we discuss in more detail the development of our framework as an instructional model (McNeill, Lizotte, Krajcik & Marx, 2006; Moje, et al., 2004), an activity structure (Kuhn, L. & Resier, 2005), and as an assessment tool to examine student work (McNeill & Krajcik, in press).

We developed our instructional model for scientific explanation to be "generic" in that it could be used across different content and contexts (McNeill et al., 2006). Yet there is a debate in the literature about the relative importance of context specific or domain specific knowledge compared to more general cognitive skills in engaging in inquiry tasks (Stevens, Wineburg, Herrenkohl, & Bell, 2005). Consequently, this lead to the research question we address in this study about whether context specific or generic support is more effective in helping students write scientific explanations.

***Context-Specific versus Generic Explanation Scaffolds***

Similar to Perkins and Salomon (1989), we do not view general cognitive knowledge and domain-specific knowledge as a dichotomy. Rather both domain specific knowledge and more general argumentation knowledge are important for students' successful construction of scientific explanations. Research suggests that an individual's success performing a scientific inquiry practice or scientific reasoning task requires both domain specific knowledge and knowledge of the general practice. For example, in Shah, Freedman and Watkins' (2004) study of expert and novice graph viewers, they found that both individuals' content knowledge and their scientific reasoning skills, influenced their ability to interpret a graph in a specific context. When students analyze data from an investigation, Kuhn, Schauble, and Garcia-Mila (1992) found that a student's ability to interpret evidence is constrained by the need to make theoretical sense of what is being observed. If a student does not understand the scientific theories or principles necessary to understand a particular task, he or she will have a difficult time drawing appropriate conclusions. A variety of research has pointed to the importance of content knowledge when students use data as evidence (Chinn & Brewer, 2001; McNeill & Krajcik, in press) and in student reasoning (Metz, 2000; McNeill et al., 2006; Zimmerman, 2000).

The question is why are both knowledge of the content and knowledge of the scientific inquiry practice important for successful practice. Koslowski argues, "…the principles of scientific inquiry are used in conjunction (not independent of) knowledge about the world. This means that the success of the principles of scientific inquiry depends on the extent to which our knowledge or theories about the world is approximately accurate…" (p. 13). For example, when Koslowski talks about evidence she stresses the importance of theories in determining, which of the many correlations or patterns in the data to consider and which are not important. Students may understand the importance of using evidence, but if they do not have strong conceptual knowledge they might not understand what counts as evidence in a particular domain. When students reason about a phenomenon, they rely on their theories about that phenomenon. Explicitly highlighting the generic nature of inquiry practices may promote student success in engaging in an inquiry task (Osborne, et al., 2003). Specifically, in terms of scientific explanation helping students understand the tacit framework of scientific explanations can support students in constructing their own explanations (Reiser et al., 2001). Consequently, when students construct scientific explanation about phenomena, what they write is influenced both by their understanding of the science content (e.g. a chemical reaction produces new substances) and their understanding of a scientific explanation (e.g. using evidence is important to justify a claim).

Yet in classroom instruction, both curriculum designers and teachers, often have to choose a particular focus. Although both an understanding of the content and scientific explanation is important for students' success in constructing scientific explanations, classroom instruction may not be able to support all aspects all of the time. Consequently, we are interested in exploring the effectiveness of different types of language in written curricular scaffolds to support students' scientific explanations. We define scaffolds as temporary supporting structures provided by people or tools to promote learning of complex problem solving. With the help of scaffolds, learners can complete more advanced activities and engage in more advanced thinking (Bransford et al., 2000). In our previous work (McNeill et al., 2006), we found that fading written curricular supports (scaffolds) that provided both context-specific and generic support resulted in greater student learning of scientific explanation than continuous written curricular scaffolds. The written curricular scaffolds did support students in writing scientific explanations. Yet we were left with the question of whether a different scaffolding format or language in the scaffold may have been more effective.

Previous research using written scaffolds and technological tools in science to promote students' written explanations has focused on *context specific* scaffolds for different explanation components (e.g. Bell & Linn, 2000; Lee & Songer, 2004; Sandoval, 2003; Zembal-Saul, et al, 2002). Context specific scaffolds provide students with hints about the task and what content knowledge to use or incorporate into their explanation. For example, Sandoval provides content scaffolds that support students in using the correct data in their natural selection explanations, such as "The factor in the environment exerting a pressure is…" (2003). Within a scaffolded computer environment, students can successfully use data as evidence in their scientific explanations to support their claims (Sandoval & Millwood, 2005). Context specific explanation scaffolds can help students understand how to apply a general inquiry practice, like scientific explanation, to a particular task. For example, while a student might have a general understanding that they need to provide "evidence", these types of context specific supports can help students understand what counts as evidence in that particular task. Furthermore, specific prompts can encourage students to connect the science content to their investigations and encourage greater meaning making (Puntambekar & Kolodner, 2005). Context-specific supports can help students develop a deeper conceptual understanding (Lee & Songer, 2004), which then influences their ability to use evidence and reason in science.

Research on explanation from other disciplines has emphasized *generic explanation* scaffolds (e.g. reading, Reznitskaya & Anderson, 2002; debate, D. Kuhn & Udell, 2001, 2003). Generic explanation scaffolds help students understand a general framework for their explanation regardless of the content area. For example, D. Kuhn and Udell (2001; 2003) in working with middle school students on debating capital punishment provided students with general scaffolds for the different components of their arguments, such as "generating reasons", "supporting reasons with evidence", and "examining and evaluating opposing-side's reasons." They found that students provided with scaffolds showed advancement not only in capital punishment debates, but also in assessments involving other social issues. Furthermore, White and Fredrickson (1998; 2000) found that their reflective scaffolds promoted student learning of inquiry practices. An examination of these scaffolds reveal that they are in fact generic prompts because the same prompts could be used regardless of the context. The scaffolds promote general metaknowledge, which is not context specific. In Wood, Bruner, and Ross' (1976) original discussion of scaffolds, they also discuss the importance of repetition. One of the factors determining their choice of tasks was "to make its underlying structure repetitive so that experience at one point in task mastery could potentially be applied to later activity, and the child could benefit from after-the-fact knowledge" (p. 91). This supports the idea of using a generic prompt, which can be repeated regardless of the content and task. This type of generic scaffold can help students' understand the thinking strategies behind constructing an explanation, such as the importance of using evidence.

Overall there has been little research comparing different types of scaffolds, especially in the scientific explanation and argumentation literature. We are interested in comparing the affordances and constraints of incorporating these different types of language into written curricular scaffolds. A previous study we conducted (McNeill et al., 2006), compared two curricular scaffold treatments, fading explanation scaffolds compared to continuous explanation scaffolds that remained constant throughout the unit. These scaffolds combined both context-specific components and generic components. The study showed that students who received scaffolds that faded over time resulted in greater learning gains for scientific explanations. The study did not find a significant difference in student content understanding across the faded and continuous groups. These results differed from another research study by Lee and Songer (2004) where they provided fifth grade students with context specific written scaffolds. They found that continuous prompts resulted in greater student learning. One possible explanation for the difference in these results is the context specific versus generic nature of the prompts. The prompts we investigated had a greater focus on generic support while the Lee and Songer prompts focused on the context-specific support. By specifically comparing these different types of scaffolds in a single instructional unit, we will be able to explore the strengths and weaknesses of the different types of prompts.

In designing the two types of scaffolds, we attempted to make the thinking strategies behind constructing an explanation clear to students in order to facilitate their understanding of how to construct one. Making scientific thinking strategies explicit to students can facilitate their use and understanding of these strategies (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999). More specifically, revealing the tacit framework of scientific explanation through scaffolds can facilitate students' explanation construction (Reiser et al, 2001). We designed the generic explanation scaffolds to reveal the general explanation thinking strategies, such as the importance of using evidence to support claims. We designed the context specific scaffolds to reveal the domain-specific strategies for each specific task, such as the importance of considering density and melting point, but not mass or volume, when trying to identify different substances. We decided in both cases to fade the support over the unit because of our previous findings that fading explanation scaffolds during this instructional unit resulted in greater learning gains for scientific explanations (McNeill et al., 2006). Fading written supports may help problematize student work. Problematizing student work makes learning tasks more difficult in the short term, but ultimately promotes student learning (Reiser, 2004).

We are interested in whether the form of the scaffold, context specific scaffold versus generic explanation scaffold, is related to student learning of both the science content as well as the inquiry practice of explanation construction. Previous studies suggest that context specific scaffolds may be more closely linked to students understand of conceptual knowledge and ability to apply that knowledge to explain a phenomenon (Lee, 2003), while generic explanation scaffolds may be more closely linked to a generalizable inquiry practice (Kuhn & Udell, 2001).

## Method

### *Instructional Context*

***Overview of curriculum***. Using a learning-goals-driven design model (Reiser, Krajcik, Moje, & Marx, 2003), we developed a middle school chemistry unit (McNeill et al., 2003) as part of the *Investigating and Questioning our World through Science and Technology* (IQWST) curriculum materials. Learning-goals-driven design uses key learning goals identified from the national standards (American Association for the Advancement of Science, 1993; National Research Council, 1996) to guide all phases of curriculum and assessment design. The IQWST curriculum materials are currently being developed in a collaborative effort by researchers at the University of Michigan, Northwestern University, the University of Illinois Urbana-Champaign, Michigan State University, and Columbia University. We used this design model to develop a 6-8 week project based unit addressing the driving question (Krajcik, Czerniak, & Berger, 1999), "How can I make new stuff from old stuff?" (referred to as *"Stuff"*) (McNeill, Harris, Heitzman, Lizotte, Sutherland & Krajcik, 2004).

*Stuff* engages students in the study of substances and properties, the nature of chemical reactions, and the conservation of matter. In the *Stuff* unit, we contextualized the science concepts and scientific inquiry practices in real world experience by focusing on making soap from fat or lard and sodium hydroxide (making new stuff from old stuff). Students complete a number of investigations where they revisit soap and fat throughout the unit. These cycles help students delve deeper into the key learning goals including both target science content and the scientific inquiry practices such as the analysis of data and construction of scientific explanations. The investigations during the unit are complemented by a student reader that has been designed based on a number of principles derived from literacy learning research and provides students with additional opportunities to extend their knowledge (The Textual Tools Study Group, in press).

***Scientific explanation in the Stuff unit.*** There is an explicit focus in the *Stuff* unit to support students in the construction of scientific explanations. In order to introduce students to scientific explanations within the context of the *Stuff* unit, we developed a focal lesson. This lesson occurred about two weeks into the unit after students collected data for the various properties of fat and soap (i.e. color, hardness, solubility, melting point, and density). First students wrote explanations using their own data and their prior understanding of scientific explanations. The students' investigation sheet for the focal lesson did not contain written scaffolds. Then the lesson called for the teacher to help the students develop a deeper understanding of scientific explanations through the use of various instructional strategies such as defining scientific explanation, modeling how to complete the practice, and providing students with feedback. Finally, students revised their explanations.

In order for students to learn how to evaluate data, they need numerous opportunities to evaluate rich, complex models of data (Chinn & Brewer, 2001; Lehrer & Schauble, 2002). Students also need numerous opportunities to engage in scientific explanations. The first reading students complete in their student reader after the focal lesson discusses why scientists construct explanations, what is included in an explanation, and provides an example of a strong explanation. The students also write approximately ten more scientific explanations during the unit depending on the teacher's enactment of the unit. Students record the results of their investigations and scientific explanations on student investigation sheets that provided students with the written curricular scaffolds.

***Written curricular scaffolds.*** In order to explore the effect of the different written supports we created two treatments: Context-Specific and Generic. We decided to fade the supports over four stages since we found in our previous research that fading written supports resulted in students constructing stronger explanations (McNeill, et al., 2006). Table 1 includes examples of the two different types of scaffolds during Stage I, which provides the most detailed support. This task is from the student reader and asks, "Using the data in the table above, write a **scientific explanation** stating whether the stones in Ring #1 and the stones in Ring #2 are the same substance or different substances." Underneath the question, students received either the context-specific or generic written scaffold. By context specific scaffolds, we mean supports that provide students with hints about the task and what content knowledge to use or incorporate into their explanation. In the example in Table 1, the context-specific scaffold provides support about the importance of using properties to determine if two stones are the same substance and provides guidance about what measurements count as properties and what measurements do not count as properties.

*Table 1: Example of Context Specific and Generic Scaffolds*

| Context Specific Scaffold | Generic Explanation Scaffold |
|---|---|
| (State whether the stones in Ring #1 and Ring #2 are the same substance. Provide whether properties, such as density, melting point, and color, are the same or different. Do not include measurements that are not properties, such as mass and volume. Tell why properties being the same or different tells you whether two stones are the same substance.) | **Claim**<br>(Write a statement that responds to the original problem.)<br>**Evidence**<br>(Provide scientific data to support your claim. You should only use appropriate data and include enough data. Appropriate data is relevant for the problem and allows you to figure out your claim. Remember that not all data is appropriate. Enough data refers to providing the pieces of data necessary to convince someone of your claim.)<br>**Reasoning**<br>(In your reasoning statement, connect your claim and evidence to show how your data links to your claim. Also, tell why your data count as evidence to support |

| | |
|---|---|
| | your claim by using scientific principles. Remember reasoning is the process where you apply your science knowledge to solve a problem.) |

Although the context-specific support does not use the language of the scientific explanation framework (e.g. claim, evidence, and reasoning), it is providing students with domain-specific hints around each component of the framework. In terms of the claim, the scaffold says, "State whether the stones in Ring #1 and Ring #2 are the same substance." The scaffold then goes onto tell students what data they should use as evidence and what data they should not use as evidence, "Provide whether properties, such as density, melting point, and color, are the same or different. Do not include measurements that are not properties, such as mass and volume." Finally, the scaffold provides support in terms of what scientific principle the student should discuss, "Tell why properties being the same or different tells you whether two stones are the same substance."

Generic explanation scaffolds help students understand the general framework for scientific explanation regardless of the content area or task. The generic scaffolds in Table 2 provide students support on what to include in a scientific explanation, the three components, as well as what each of those components means. For example, the evidence scaffold provides students with support about including only appropriate data and including enough data. The generic scaffold would be the same regardless of the content and context of the task.

The students had the possibility of being exposed to the written curricular scaffolds nine times during the unit with the support provided by the scaffolds fading over four stages. Appendix A describes the investigations where students wrote scientific explanations and lists the corresponding stage. Appendix B provides an example of both a context-specific scaffold and a generic scaffold for each of the four stages illustrating how the support faded over time.

***Study Design***

In order to test the effect of the written curricular scaffolds on student learning, we used a quasi-experimental design that included comparison groups with both pre and posttests (Shadish, Cook, & Campbell, 2002). Six teachers agreed to be a part of the study all of which had at least two classes of $7^{th}$ grade students. We assigned the scaffold treatment to create the two comparison groups. This assignment occurred by class since students interact with other students within the same class, often working with different students on classroom activities. If two students worked together with different written scaffolds, the written scaffolds may influence the student who had not received that treatment. Furthermore, the teachers often have full class discussions about the students' explanations, which could result in a discussion of the scaffolds. Consequently, we decided to randomly assign classes of students to either the Context-Specific or Generic treatments so that teachers with multiple classes taught both groups. For example, if a teacher had four classes, two classes received student investigation sheets with Context-Specific explanation scaffolds and two classes received Generic explanation scaffolds. In order to examine student learning and achievement, we analyzed students' written explanations on identical pre and posttests.

***Participants***

The participants in this study included six teachers from six different schools in the Mid-west. Table 2 provides the type of school and the number of students for each teacher.

*Table 2: Participants in the Study*

| Teacher | Type of School | Number of 7th Grade Classes | Total Number of Students |
|---|---|---|---|
| Ms. Kittle | Urban Public | 5 | 164 |
| Ms. Marshall | Urban Public | 5 | 162 |
| Ms. Hill | Urban Public | 2 | 66 |
| Mr. Kaplan | Urban Public | 4 | 71 |
| Ms. Foster | Urban Charter | 2 | 49 |
| Ms. Nelson | College Town Independent | 4 | 56 |
| Total | | 22 | 568 |

The first five teachers all taught in the same large urban area while the last teacher taught in a large college town. Four of the schools in the large urban area were public while one was charter school. The school in the large college town was an independent school. The specific demographic data for these schools is listed in Table 3.

*Table 3: School Demographic Data for 2004-2005*

| Teacher | Type of School | Ethnicity | % Eligible for free or reduced lunch |
|---|---|---|---|
| Ms. Kittle | Urban Public[1] | 94% African American<br>5% Asian<br><1% Caucasian | 74% |
| Ms. Marshall | Urban Public[1] | 99% African America<br><1% Asian<br><1% American Indian<br><1% Hispanic | 90% |
| Ms. Hill | Urban Public[1] | 99% African America<br><1% Caucasian<br><1% American Indian<br><1% Hispanic | 84% |
| Mr. Kaplan | Urban Public[1] | 95% African America<br>3% Caucasian<br>1% Hispanic<br><1% American Indian | NA |
| Ms. Foster | Urban Charter[1] | 100% African American | 73% |
| Ms. Nelson | College Town[2] Independent | 75% Caucasian<br>8% Asian<br>7% African American<br>6% Multiracial | NA – 20% of student body receives financial aid for tuition |

[1] This information was obtained from the MI Department of Education through www.greatschools.net
[2] This information was obtained from the independent school's website.

As you can see from this information, the majority of students in the schools in the large urban area were African American and from lower income families. Although Ms. Foster taught in a charter school, the students attending her school came from a similar population as the public school students. Ms. Nelson taught in an independent middle school in a large college town. The majority of the schools in the independent school were Caucasian and from middle to upper-middle income families.

***Data Sources***

In order to assess student learning, we collected pre and posttests. All students completed identical pre and posttest measures that included 15 multiple-choice items and 3 open-ended scientific explanations. The multiple-choice items serve as a measure of students' understanding of the content learning goals independent of students' ability to use that understanding in the construction of scientific explanations. The multiple-choice items covered the three key content learning goals of the unit: substance and properties, chemical reactions, and conservation of mass (See Appendix C for sample questions). Multiple-choice responses were scored and tallied for a maximum possible score of 15. In order to check the reliability of the multiple-choice items to determine whether the items were internally consistent and measuring a single latent variable, we calculated Cronbach's alpha. For students' scores on the posttest multiple-choice items, Cronbach's alpha is 0.777 suggesting that the items represent a valid measure of students' conceptual knowledge.

The open-ended explanation items on the test serve as a measure of students' ability to construct scientific explanations. The explanation items ask students to write scientific explanations for the three different content areas: substance and properties, chemical reactions and conservation of mass. The three explanation items were scored using rubrics. We scored all student explanations by adapting our base explanation rubric (see Appendix D). A base rubric is a general rubric for scoring an inquiry practice across different content and learning tasks. We used our base rubrics to develop *specific* rubrics for assessing students on each learning and assessment task for our chemistry unit (See McNeill & Krajcik, in press for a discussion of the rubrics and scoring of student work). All questions were scored by one rater. We then randomly sampled 20% of the student sheets and a second independent rater scored them. The inter-rater agreement was 98% for claim, 94% for evidence, and 98% for reasoning across the three explanation items. As a second check of the reliability of the explanation scores as a valid measure, we calculated Cronbach's alpha. For students' scores on the posttest scientific explanations, Cronbach's alpha is 0.809 suggesting that the explanation items represent a valid measure of students' understanding.

## Results

Our analyses address four research questions: 1) Do students' written explanations improve during the unit, if so, in which of the components (claim, evidence, reasoning)? 2) Is there a relationship between students' understanding of scientific explanation and their understanding of the content? 3) Do the written scaffold treatments (context-specific versus generic) effect student learning of scientific explanation? and 4) Do the written scaffold treatments (context-specific versus generic) effect student learning of the science content?

***Student Learning for Explanation***

First, we examined students' overall learning for scientific explanations during the Stuff unit. This was obviously an important initial base line, because if students were not learning during the unit we could not investigate the influence of the curricular scaffolds on student learning. We conducted paired t-tests for all students who completed both the pre and posttests. Because of high absenteeism in the urban schools only 328 students completed both the pre and posttests. We examined students' claim, evidence, and reasoning scores separately to see if greater learning occurred for one component compared to another. Each component was weighted for a maximum possible score of 3.0 for each explanation. Since the test included three scientific explanations, the highest overall possible score was 9.0 for each component and 27.0 for the total possible score. The results from this analysis are below in Table 4.

*Table 4: Overall student learning of scientific explanation (n=328)*

| Score type | Maximum | Pretest *M* (*SD*) | Posttest *M* (*SD*) | *t* (327) [a] | Effect size [b] |
|---|---|---|---|---|---|
| Composite Score | 27.0 | 4.66 (3.87) | 9.57 (6.85) | 15.01*** | 1.27 |
| Component | | | | | |
| Claim | 9.0 | 2.74 (2.72) | 4.39 (3.13) | 9.35*** | 0.61 |
| Evidence | 9.0 | 1.78 (1.66) | 3.17 (2.47) | 10.33*** | 0.84 |
| Reasoning | 9.0 | 0.14 (0.49) | 2.01 (2.35) | 14.88*** | 3.82 |

[a] One-tailed paired *t*-test
[b] Effect size is the difference between pretest *M* and posttest *M* divided by pretest *SD*.
*** $p < .001$

Across both scaffold treatments, students are achieving significant learning gains for scientific explanation as a whole as well as for each component. The effect sizes for student learning vary across the components with the greatest effect size for reasoning, though the average reasoning posttest score is the lower than the claim and evidence average. Overall, the learning gains are impressive yet there also appears to be room for improvement. Consequently, we were interested in whether one of the scaffold treatments appeared to be related to greater student learning of scientific explanation over the unit.

***Relationship Between Content and Explanation***

We also examined if there was a correlation between students' content knowledge (as measured by the multiple-choice) and their scientific explanations for each of the three content areas: substance and property, chemical reactions, and conservation of mass. This allowed us to investigate the relationship between content knowledge and students' ability to construct scientific explanations. We determined the correlations between students' posttest multiple-choice and explanation scores for each content area. Not surprisingly, there was a relationship between these two scores. Table 5 shows these results.

*Table 5: Correlations Between Science Content and Scientific Explanation (n=328)*

| Content Area | Claim | Evidence | Reasoning |
|---|---|---|---|
| Substance & Properties | 0.37** | 0.33** | 0.48** |
| Chemical Reactions | 0.75** | 0.45** | 0.53** |
| Conservation of Mass | 0.46** | 0.41** | 0.39** |

** $p < .01$

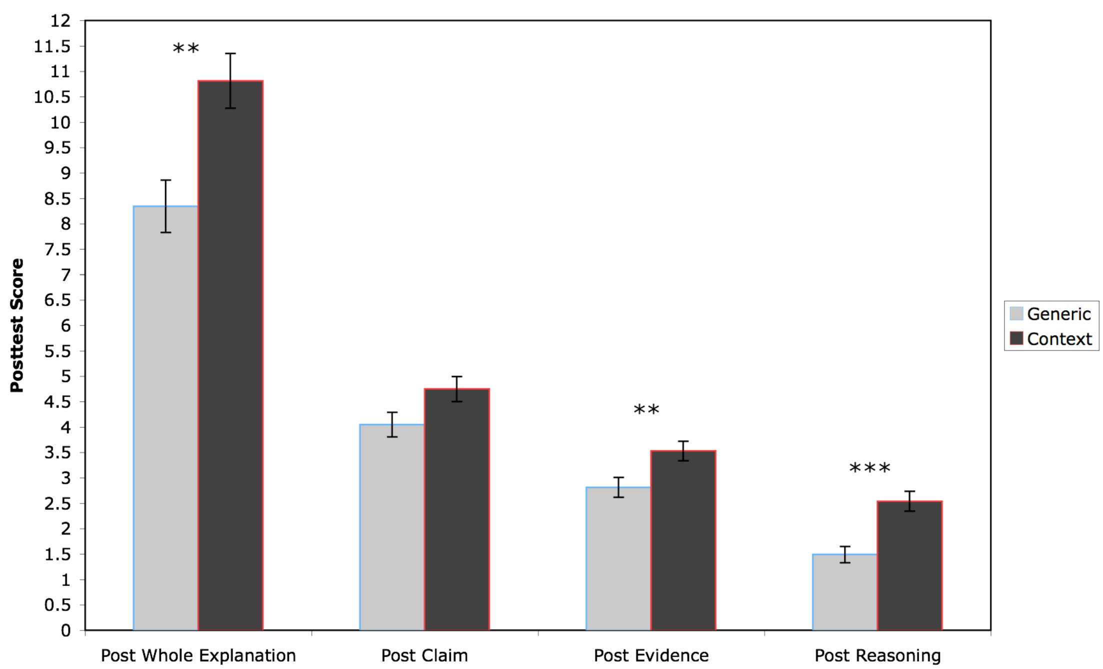
Students who had higher multiple-choice scores in a content area also had higher explanation scores in that area.

***Influence of Curricular Scaffolds on Scientific Explanation***

Next, we explored the effect of the written curricular scaffolds on student learning of scientific explanation. To address this question, we examined students' written explanations on the pre and posttests. We examined whether the curricular scaffold treatment (context-specific versus generic) had a significant effect on student learning over the *Stuff* unit by using students' pre and posttest explanation scores. We conducted an analysis of covariance, ANCOVA, with the Scaffold Treatment (context-specific versus generic) as the fixed factor, the scientific explanation pretest score as the covariate, and the scientific explanation posttest score as the outcome variable. We ran this analysis four times, one with the total explanation score and then with the claim, evidence, and reasoning scores separately. This allowed us to determine the effect of the curricular scaffolds and to see if it varied by explanation component.

The effect of the curricular scaffold was significant for the whole explanation, evidence, and reasoning scores in each case the context-specific group (n = 163) demonstrated greater learning than the generic group (n=165)[1]. Figure 1 displays the differences in the two treatment groups. For the entire explanation, the context specific group had higher posttest scores after controlling for any differences in the pretest $F(1, 325) = 11.84, p < .01$. When we broke the analysis down by component, we found that for both evidence, $F(1, 325) = 7.11, p < .01$, and reasoning, $F(1, 325) = 14.43, p = .001$, the context specific group had greater posttest scores after controlling for the covariate.

**Figure 1: Effect of Scaffold Treatment on Posttest Explanations**




This suggests that students that received the context-specific curricular scaffold learned more in terms of their ability to write explanations. Both students' evidence and reasoning scores improved more during the *Stuff* unit if they received the context-specific supports. Interestingly to note, students' evidence and reasoning scores both begin and end lower compared to their claim scores. Similar to our previous work (McNeill & Krajcik, in press; McNeill et al., 2006), the claim appears to be the easiest component for students.

[1] For all three ANCOVAs presented, the effects of covariates are significant and the interaction between the covariate and the scaffold treatment is not significant.

***Influence of Curricular Scaffolds on Science Content***

As we discussed previously, we found that there was a correlation between students' content knowledge and their ability to construct scientific explanations. Consequently, we were interested in whether the effect of the written scaffolds was the result of a greater understanding of the science content or a more general understanding of how to construct a scientific explanation. To investigate this question we compared students' learning of the content knowledge for the two treatment groups: Context-Specific vs. Generic. We performed an ANCOVAs on students' posttest multiple-choice scores; Scaffold Treatment (context-specific vs. generic) was the fixed factor and the pretest multiple-choice score was the covariate. The effect of the explanation scaffolds was also significant on students' learning of the science content. For the multiple-choice items, the context specific group had higher posttest scores after controlling for any differences in the pretest $F\ (1, 325) = 3.97, p < .05$. Figure 2 displays this result.

**Figure 2: Effect of Scaffold on Content Knowledge**

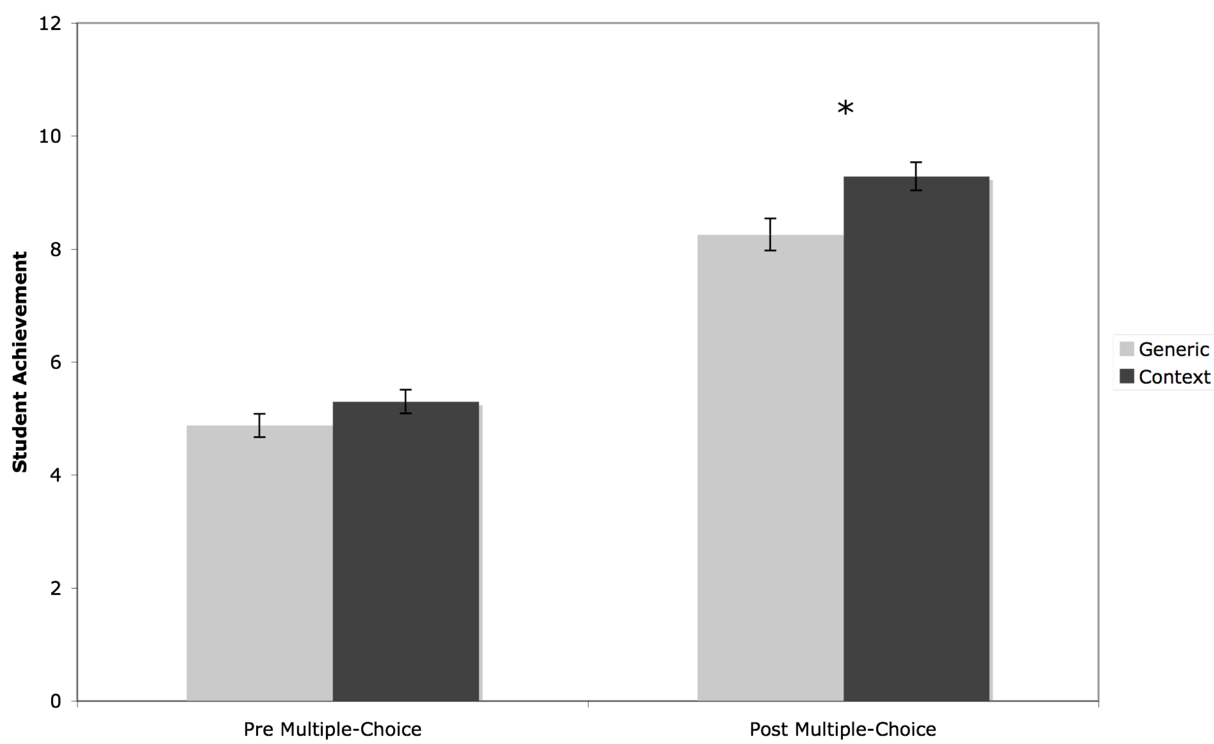



Figure 2 shows that while there was no significant difference in the content knowledge of the two groups before the unit, after the unit the context-specific group had stronger content knowledge. The context-specific scaffolds resulted in greater student learning in terms of both their written explanations and their understanding of the content as measured by the multiple-choice items. This leads to the question of whether the greater increase in the context-specific groups' understanding of scientific explanation is a result of a greater understanding of explanation or if it is just a result of their greater understanding of the content knowledge. Since both an understanding of content and an understanding of explanation are important for students' success at writing scientific explanations, this is a difficult distinction to tease apart.

## Discussion

Written scaffolds embedded in curriculum materials can promote student learning of scientific inquiry practices (White & Frederiksen, 1998; 2000). Although research has provided important lessons about the design of scaffolds, many questions still remain (Davis & Miyake, 2004). In terms of scientific inquiry practices, both knowledge of science content and knowledge of scientific inquiry are important for students' successful completion of an inquiry practice (Metz, 2000). Consequently, we investigated whether context-specific scaffolds or generic explanation scaffolds resulted in greater student learning of how to write a scientific explanation.

We found that students' written scientific explanations improved over the *Stuff* unit in which students were provided explicit support for scientific explanation both in the written curricular materials and by the teachers in their instructional strategies. We also found that there was a correlation between students' achievement for their written scientific explanations and their understanding of the science content as measured by the multiple-choice items. This finding is similar to what other researchers (Chinn & Brewer, 2001; Metz, 2000; Zimmerman, 2000) have found in terms of the importance of both domain specific knowledge and more general knowledge of scientific inquiry in students successful performance of a scientific inquiry practice.

When we examined the effect of the curricular scaffolds, we found that the context-specific scaffolds resulted in greater student learning of scientific explanation, particularly in terms of the evidence and reasoning components, over the course of the unit. We also examined students' content knowledge to investigate whether this effect was just the result of a stronger understanding of how to construct scientific explanations or if students' stronger understanding of the content also influenced it. Although students' content knowledge in the two treatment groups did not vary before the unit, there was a significant difference after the unit. The context-specific group developed a stronger understanding of the content knowledge over the course of the unit compared to the generic group. Consequently, the context-specific written supports resulted in greater student learning of both scientific explanation and the science content. This lead us to two questions: 1) Why did the context-specific scaffolds that were specifically designed to support student learning of scientific explanation also result in a stronger understanding of the science content? and 2) Why were the context specific scaffolds more effective than the generic explanation scaffolds?

Reflecting back on the written curricular scaffolds (see Table 1), it makes sense that the context-specific scaffolds would help students develop a stronger understanding of the content. For example, the scaffold provided in Table 1 would help students' understand that density, melting point and color are properties, while mass and volume are not properties. This distinction about what does and does not count as a property is a key content learning goal in the unit. This written support makes salient the content knowledge students need to apply to this particular learning task and could promote their learning of the science content, because students actively use the science concepts in the construction of explanations. Developing a deeper understanding of the science concepts would help students respond correctly to the multiple-choice items on the test. For example, a sample of multiple-choice items is shown in Appendix C. Understanding the importance of properties and what counts as a property could help students' answer multiple-choice questions 1, 3, and 12. Consequently, although the intent of the context-specific scaffolds was to help students' understand how to construct a scientific explanation for a particular context, the curricular supports also promoted a general understanding of the key science concepts.

The question remains why the context-specific scaffolds were more effective than the generic explanation scaffolds. Similar to our findings, previous research has found that context-specific or domain-specific scaffolds can help students construct explanations. For example, Sandoval (2003) found that providing students with prompts that offered domain-specific guidance helped students write explanations that were appropriate for their inquiry in natural selection. Lee and Songer (2004) also found that providing students with context-specific scaffolds within an inquiry-oriented curriculum resulted in students writing stronger explanations where they justified their claims with evidence. Yet other previous research (Reznitskaya & Anderson, 2002; debate, D. Kuhn & Udell, 2001, 2003) found that generic prompts resulted in greater student learning of explanation and argumentation.

Our current hypothesis of why the context-specific supports were more effective is because the students in both treatments developed an understanding of the general explanation framework through classroom instruction. Besides the written curricular scaffolds, the teachers provided students with support around constructing scientific explanations using the explanation framework. In our previous work (McNeill & Krajcik, in review), we found that when teachers discussed the rationale behind scientific explanation in combination with defining scientific explanation as claim, evidence, and reasoning and discussing each of the components resulted in greater student learning of scientific explanation. The generic explanation scaffolds define scientific explanation and discuss each of the three components. If the teacher provided this generic support to her students in classroom discussions, then the generic scaffolds may have become redundant, which might be why they were not as effective. On the other hand, the context-specific scaffolds may have provided further support beyond the general support provided by the teacher in class. Tabak (2004) discusses the idea of distributed scaffolding where a collection of curriculum materials, instructional strategies, and activity structures work collectively to support learners. Currently, we are analyzing videotapes from the six teachers enactment of the curriculum materials to determine what instructional strategies teachers used in their classrooms, the quality of those strategies, and whether there is an interaction between the effect of the written curricular scaffolds and the teacher enactment.

In terms of the effectiveness of the context-specific scaffolds, there is also the question of whether these scaffolds just promoted students' understanding of the content or if they also promoted students' understanding of how to construct scientific explanations. Besides developing an understanding of the content, the context-specific scaffolds may also have helped students understand what counted as evidence or what counted as reasoning for a particular task. Perhaps students developed a general understanding of the scientific explanation framework from teacher instructional practices and classroom discussions. The context-specific scaffolds may have helped students understand how to apply the framework to a particular task. It is also possible that if we had assessed students using a more distal measure we might have seen a different effect of the curricular scaffolds in terms of students' ability to transfer their understanding of scientific explanation to a new setting. Unfortunately, our data sources and analysis do not allow us to determine whether or not that occurred. Recent research (Gotwals & Songer, 2006; Wilson, 2005) on psychometric models is helping to develop more effective assessment systems to tease apart students understanding of science content and scientific inquiry.

Another question that remains is how students' used the curricular scaffolds. Just examining the outcomes does not provide a measure of the process that occurred when students constructed explanations. In order for a tool to be used as an intellectual partner requires *mindfulness* not *mindlessness*. When a learner is mindful, they are engaged in the task and are not relying on automatized processes. (Salomon, Perkins & Globerson, 1991) It is important to consider how students are interacting with the tool. This type of mindful engagement can result in improved performance. In future work, we would like to examine more closely how students actually used the written curricular scaffolds. We conducted individual think-alouds with a subset of students who were a part of this study. We plan to analyze these think-alouds to gain insight into how students used both the context-specific and generic scaffolds. These will also provide another measure of whether either the generic or context-specific scaffolds helped students' develop a richer understanding of scientific explanation that they could than transfer and use in a new situation.

Our results from this study in combination with previous research suggest to us that perhaps the word "scaffold" is not appropriate for the context-specific written support provided by the curriculum materials. In our previous work (McNeill et al., 2006), we define scaffolds as temporary supporting structures provided by people or tools to promote learning of complex problem solving. This idea of scaffolds being *temporary* or that they should *fade* over time is an essential characteristic that makes a support a scaffold rather than a cognitive tool (Salomon, Perkins, & Globerson, 1991) or cultural tool (Tabak, 2004). A cognitive tool is a support that should remain a part of the instructional setting to promote student learning. Lee and Songer (2004) previously found that context-specific supports were more effective if they did not fade in curriculum materials, while we (McNeill et al., 2006) found written supports that focused more on the generic nature of a scientific explanation were more effective if they did fade.

In our design of our context-specific supports in this study, each support was unique as it was specific to the content area and task. This differed from the generic scaffolds, which always focused on the general framework of claim, evidence, and reasoning. Perhaps because these context-specific supports were unique in every setting, students depended on them throughout the unit, while with the generic supports they were able to internalize the general explanation framework. Consequently, the context-specific written supports would not scaffolds, but rather cognitive tools because they should not fade over time. Making this distinction between a scaffold and a cognitive tool may seem simply like semantics. But in designing instructional materials and learning environments it is important to consider what supports should remain constant and what supports should fade over time to promote greater student learning. Fading supports can problematize a task for students resulting in learning tasks being more difficult in the short term, but ultimately promoting greater student learning (Reiser, 2004). Consequently, it may be detrimental to student learning to have some supports remain constant in the instructional design. The supports may become crutches for the students and they may not be able to achieve the same level of proficiency independently. On the other hand, it can also be harmful to remove a support that a student still needs. In the case of the context-specific supports, the fact that they were unique for every task may have been why they promoted greater student learning than the generic supports. Since each content area and task was new for students, they may have needed that support to help them develop a deeper understanding of the content as well as how to apply the general framework of scientific explanation to the particular task. Consequently, our decision to fade the context-specific supports may have been inappropriate. The context-specific support may have been more effective not as scaffolds that faded over time, but rather as cognitive tools that provided students with unique support in the different contexts over time.

Classrooms are complex systems where many factors influence student learning including tools, teachers, and peers (Lampert, 2002). It is important to consider the different factors that are providing support (e.g. curriculum versus teacher), the type of support they are providing (e.g. context specific vs. generic), and the most effective way to provide that support over time (e.g. fade vs., continuous). This study suggests that during the enactment of an inquiry oriented unit with an explicit focus on scientific explanation, that providing context-specific written supports can promote greater student learning of the science concepts and the ability to write scientific explanations using those science concepts.

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## Appendix A: Explanations During the Unit

| Scaffold Stage | Content Area | Learning Task |
|---|---|---|
| No Scaffolds | Substance & Property | Activity 6.1: Students determine if soap and fat are the same or different substance based on their previous investigations where they collected data on a variety of properties. |
| Stage I | Substance & Property | Reader 6.1: Students are provided with data on two different stones and determine whether they are the same substance. |
| | Substance & Property | Activity 7.1: Students mix together a number of substances and have to determine if a new substance is formed. |
| | Chemical Reaction | Reader 7.1: Students are provided with the properties for the substances they mixed in class and have to determine if a chemical reaction occurred. |
| Stage II | Chemical Reaction | Activity 8.2: Students investigate what happens when a penny and vinegar are combined and determine whether a chemical reaction occurred. |
| | Chemical Reaction | Activity 10.1: Students investigate whether boiling is a chemical reaction. |
| | Chemical Reaction | Activity 10.2: Students investigate whether combining powdered drink mix and water is a chemical reaction. |
| Stage III | Conservation of Mass | Optional Activity 13A: Students combine different substances in a chemical reaction to form “gloop” and have to determine whether mass changes. |
| | Conservation of Mass | Activity 13.1: Students react Alka Seltzer and water in an open container and determine whether the mass changes. |
| | Conservation of Mass | Activity 13.2: Students react Alka Seltzer and water in a closed container and determine whether the mass changes. |
| Stage IV | Conservation of Mass | Reader 13.2: Students are provided with the mass of reactants and products before and after a chemical reaction and determine whether the mass changes. |
| | Substance | Activity 15.1: Students collect data to determine whether they formed a new substance when they mixed fat and sodium hydroxide solution. |
| | Better Soap | Optional Activity 16.A: Students collect data to determine whether their soap performs better than store bought soap. |

## Appendix B: Scaffolds During the Unit

| Scaffold Stage | Learning Task | Context-Specific Scaffold | Generic Scaffold |
|---|---|---|---|
| Stage I | Activity 7.1 | (State whether new substances were formed after combining the baking soda, powdered sugar, road salt, and phenol red in solution. Provide whether properties, such as color, are the same or different. Also, provide whether there were any signs of a chemical reaction, such as temperature change or a gas being produced. Tell why properties being the same or different tells you whether new substances were formed.) | **Claim**<br>(Write a statement that responds to the original problem.)<br>**Evidence**<br>(Provide scientific data to support your claim. You should only use appropriate data and include enough data. Appropriate data is relevant for the problem and allows you to figure out your claim. Remember that not all data is appropriate. Enough data refers to providing the pieces of data necessary to convince someone of your claim.)<br>**Reasoning**<br>(In your reasoning statement, connect your claim and evidence to show how your data links to your claim. Also, tell why your data count as evidence to support your claim by using scientific principles. Remember reasoning is the process where you apply your science knowledge to solve the problem.) |
| Stage II | Activity 8.2 | (State whether combining the copper penny and vinegar is a chemical reaction. Provide properties to support whether or not a chemical reaction occurred. Tell why using properties is important.) | **Claim**<br>(Respond to the problem.)<br>**Evidence**<br>(Provide scientific data to support your claim. You should only use appropriate data and include enough data.)<br>**Reasoning**<br>(Connect yout claim and evidence. Tell why your data counts as evidence using scientific principles.) |
| Stage III | Activity 13.2 | Tell how conservation of mass and open/closed system is related to why the mass stayed the same or changed. | Remember to include claim, evidence, and reasoning. |
| Stage IV | All | No Scaffold | No Scaffold |

## Appendix C: Sample Multiple-Choice Items

**Substance and Property:**

12. A property is
    A. determined by the amount of a substance.
    B. made of one type of substance.
    C. a process to make a new substance.
    D. a characteristic of a substance.

3. A student found 2 green powders that look the same. He wants to figure out if the 2 powders are the same or different substances. Which of the following is the best method to use?
    A. Measure the mass, volume, and temperature of each powder and compare.
    B. Combine both green powders and see if there is a chemical reaction.
    C. Mix the 2 green powders together and then test the properties.
    D. Determine the density, solubility, and melting point of each powder and compare.

**Chemical Reaction:**

1. To determine if a chemical reaction occurred, you should measure and compare which of the following?
    A. volume of the materials
    B. shape of the products
    C. properties of the substances
    D. mass of the reactants

5. Which of the following is an example of a chemical reaction?
    A. mixing lemonade powder with water
    B. burning marshmallows over a fire
    C. melting butter in a pan
    D. boiling water on a stove

**Conservation of Mass:**

11. Which statement is always true about conservation of mass?
    A. The total mass of the reactants is equal to the total mass of the products.
    B. The mass of one reactant is equal to the mass of one product.
    C. The total mass of a system changes in a chemical reaction.
    D. The mass changes in a phase change, but not in a chemical reaction.

7. A student performs the same chemical reaction experiment twice — once in an open system, and again in a closed system. The mass before the chemical reaction is 13 grams. The chemical reaction produces a gas. What would you expect the mass to be after the chemical reaction in the open and closed systems?

A. 13 grams in the open system and 15 grams in the closed system
B. 13 grams in the open system and 11 grams in the closed system
C. 11 grams in the open system and 13 grams in the closed system
D. 11 grams in the open system and 15 grams in the closed system

## Appendix D: Base Explanation Rubric

| Component | Levels | | |
|---|---|---|---|
| | **0** | **1 & 2** | **3** |
| **Claim –** An assertion or conclusion that answers the original question. | Does not make a claim, or makes an inaccurate claim. | Makes an accurate but incomplete claim. | Makes an accurate and complete claim. |
| **Evidence** – Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim. | Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim). | Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence. | Provides appropriate and sufficient evidence to support claim. |
| **Reasoning** – A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient scientific principles. | Does not provide reasoning, or only provides reasoning that does not link evidence to claim. | Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient. | Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles. |