Relationship Between Teacher Instructional Practices and Curricular Scaffolds in Supporting Students in Writing Scientific Explanations

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Abstract

We investigated how two different curricular scaffolds (context-specific vs. generic), teacher instructional practices, and the interaction between these two types of support influenced student learning of scientific explanations. This study focuses on an eight-week middle school chemistry curriculum that was enacted by six teachers with 578 students during the 2004-2005 school year. Analyses of identical pre and posttests and videotapes of teachers' enactments revealed that the curricular scaffolds and teacher instructional practices were *synergistic* in that the effect of the written curricular scaffolds depended on the teacher's enactment of the curriculum. The context-specific curricular scaffolds were more successful in supporting students in this complex task, but only when teachers' enactments provided generic support for scientific explanation through instructional practices.

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In a dynamic and complex classroom environment, not all of the support for a learning goal can come from one scaffold (Puntambekar & Kolodner, 2005). Tabak (2004) introduces the idea of synergy where students receive support from multiple co-occurring and interactive means. These different supports include curricular scaffolds, but also other forms such as the teacher and student peers. Our work focuses on supporting students in one particular inquiry practice, scientific explanation. Our goal is to help students construct scientific explanations about phenomena in which they justify their claims using appropriate evidence and reasoning. Previous work in this area stresses the importance of assisting students in engaging in this complex practice (Driver, Netwon, & Osborne, 2000; Duschl & Osborne, 2002), and that justifying claims does not come easily to students (McNeill, Lizotte, Krajcik & Marx, 2006; Sadler, 2004; Sandoval & Millwood, 2005). In this study, we investigate how the language of written curricular scaffolds (context-specific vs. generic), teacher instructional practices, and the interaction between the two, support student learning of scientific explanations.

Conceptual Framework

Importance of Explanation and Argumentation

Over the past twenty to thirty years, the image of science has shifted from lone scientists conducting experiments to a social enterprise in which a community works collaborative to engage in problem solving and the formulation of explanations about phenomena (Duschl, Schweingruber, & Shouse, 2006). Science is fundamentally about explanation (Nagel, 1961) and argumentation (Driver, Newton & Osborne, 2000). Engaging students in this scientific practice is essential for helping students develop scientific literacy and has the potential of many positive outcomes in terms of students ability to construct explanations, develop a richer understanding of the content, and alter their views 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. 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 we conducted with our colleagues (McNeill et al., 2006), we found that engaging students in an eight week unit in which 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 our work 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 in which a key focus of instruction is writing scientific explanations (McNeill & Krajcik, in press a). In Zohar and Nemet's (2002) work, 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 compared to 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. Another possible reason for explanation and argumentation increasing students' understanding of the science content is the "self-explanation effect" (Chi, Bassok, Lewis, Reimann & Glaser, 1989). Chi and her colleagues (1989) found that when students explained phenomena to themselves they justified actions and related them to science principles, which resulted in learning and encoding new knowledge. This act of making meaning and justifying a phenomenon can help students develop a stronger understanding of the science principles. These studies suggest that instructional units focused on explanation and argumentation can promote students' understanding of science concepts, perhaps better than more traditional units.

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). Engaging in argumentation where students socially construct and justify 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 for a single unit might not be enough. Rather the curriculum materials, teacher, other supports, and sufficient time may be critical in whether and how engaging in explanation changes students' views of the nature of science.

Instructional Framework for Scientific Explanation

For our work with middle school teachers and students, we developed an instructional framework in order to make explicit the components of explanation and argumentation that are often implicit (Reiser et al., 2001) and to simplify the task to make it more accessible for teachers and students (Quintana et al., 2004). Like many other science education researchers (Bell & Linn, 2000; Driver, et al., 2000; Erduran, Simon & Osborne, 2004; Jiménez-Aleixandre, Rodríguez & Duschl, 2000; Sandoval, 2003; Zembal-Saul, et al., 2002), we began by adapting Toulmin's (1958) mode of argumentation. We simplified this model to develop our framework for scientific explanation that consists of three components: claim, evidence and reasoning. The claim is an assertion or conclusion about a question or problem. Evidence is the scientific data that needs to be both appropriate and sufficient to support the claim. This evidence can either come from data the students collect themselves or second hand data such as information available online or in books. Finally, the *reasoning* is a justification for why the data counts as evidence to support the claim. The reasoning articulates the logic behind the link between the evidence and claim which often includes appropriate scientific principles. In other work (McNeill et al., 2006; Moje et al., 2004), we discuss our rationale for the instructional framework in more detail. In this study, we were interested in how curricular scaffolds and teacher instructional practices that were informed by this framework influenced students' ability to write scientific explanations.

Domain-specific versus Domain-general knowledge

In developing the instructional framework of claim, evidence, and reasoning, our intention was to use the framework with middle school students across different science domains (e.g. chemistry, biology, earth science and physics). There is a debate in the literature about the relative importance and role of domain-specific knowledge compared to more domain-general knowledge in engaging in inquiry tasks (Stevens, Wineburg, Herrenkohl & Bell, 2005). Domain-specific knowledge refers to the concepts and strategies individuals develop in various content domains such as English, biology or even chess or politics. For example in the domain of physics, researchers have investigated children's understanding of a variety of concepts such as gravity, motion, energy, and electricity.

Domain-general knowledge refers to concepts and strategies that can be used across domains such as general cognitive skills or problem solving abilities. In science, researchers discuss domain-general reasoning or inquiry practices that can be used across the different scientific domains (Schunn & Anderson, 1999; Zimmerman, 2000). For example, they discuss domain-general expertise in science such as designing experiments (Zimmerman, 2000), controlling variables (D. Kuhn, Schauble, & Garcia-Mila, 1992), constructing arguments (Driver et al., 2000; D. Kuhn, 1993) and relying on evidence to justify claims (Schunn & Anderson, 1999). We developed our instructional model of scientific explanation to be domain-general for science so that middle school students and teachers could use it in chemistry, physics, earth science, and biology. Across these different science domains, the generic scientific explanation instructional model may help support students in constructing explanations about phenomena in which they justify their claims with evidence and reasoning.

Traditionally research has focused on domain-specific and domain-general knowledge in isolation. Similar to other researchers (Perkins & Salomon, 1989; Schunn & Anderson, 1999), we do not view domain-general expertise and domain-specific expertise as a dichotomy. Rather there is a continuum from more general knowledge to domain-specific knowledge. Furthermore, recent research argues that a variety of knowledge is important for successful engagement in reasoning or inquiry tasks (Duschl et al., 2006; Gotwals & Songer, 2006; Perkins & Salomon, 1989; Schunn & Anderson, 1999; Zimmerman, 2000). Although the scientists in all domains ask questions and use evidence, domain-specific knowledge determines the types of questions asked and what counts as evidence (Passmore & Stewart, 2002; Sandoval, 2003). Both content knowledge and scientific reasoning skills are important for students' successful completion of a particular science problem, like determining the features that influence a boat's speed (D. Kuhn, Schauble & Garcia-Mila, 1992). 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 influence their ability to interpret a graph in a specific context.

The question is why are both knowledge of the domain 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…" (1996, p. 13). For example, when Koslowski talks about evidence she stresses the importance of theories or principles 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 or principles about that phenomenon. When they are then asked to articulate a scientific explanation about that phenomenon, what they write is influenced both by their application of scientific principles to the phenomenon (e.g. understanding of chemical reactions) and what they think they need to include in their written explanation (e.g. they need to include evidence to justify their claim).

Explicitly highlighting the generic nature of inquiry practices, such as constructing explanations, may help students construct a more accurate picture of the nature of science (Osborne, Collins, Ratcliffe, Millar & Duschl, 2003). Using this general framework does simplify the complex task of constructing an explanation and opens the possibility of misrepresenting it. Yet, the benefits of using this explanation model may outweigh the drawbacks. This connects to Ann Brown and her colleagues' (1993) definition of authentic practice, which should align with practitioner culture, but it might not necessarily be identical to what scientists do, because classroom practice should consider the needs and interests of the students. We created our framework for scientific explanation as an instructional model that takes into consideration the needs of both teachers and students. Building generic frameworks for scientific inquiry practices, such as scientific explanation, offers students' greater access and understanding of science as a way of knowing.

Context-Specific versus Generic Explanation Scaffolds

Scaffolds are temporary supporting structures afforded by tools or individuals to promote student learning of complex problem solving or reasoning (McNeill et al., 2006). Considering the different types of knowledge involved in the successful completion of a scientific explanation is important in designing effective written curricular scaffolds. 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 focus on 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 in writing scientific explanations. Specifically, we are interested in investigating the effects of two different types of curricular prompts that we call *context-specific* and *generic* explanation scaffolds. We chose the phrase context-specific and not domain-specific scaffolds because the prompts provide students with hints about the task and what content knowledge to use or incorporate into their scientific explanation. The prompts do not just include science content from a particular domain, but rather the prompts are targeted to provide hints about how to apply that content knowledge in a particular context to write a scientific explanation. We refer to the other type of prompt as generic explanation scaffolds and not domain-general scaffolds so as not to suggest that these scaffolds apply across all domains (e.g. English, history, chess). Rather the generic explanation scaffolds are targeted specifically for science and specifically to meet the needs of middle school students. Generic explanation scaffolds help middle school students understand a general framework for their scientific explanations regardless of the science content area.

Previous research using written scaffolds and technological tools in science to promote students' written explanations has focused on *context-specific* scaffolds (e.g. Bell & Linn, 2000; Lee & Songer, 2004; Sandoval, 2003; Zembal-Saul, et al., 2002). As we mentioned previously, context-specific prompts provide students with hints about how to use their conceptual understandings to construct scientific explanation. For example, Sandoval provided software scaffolds that focused on the content and context in that they supported students in using the correct data in their natural selection explanations, such as "The factor in the environment exerting a pressure is…" (2003). Within this scaffolded computer environment, students successfully used 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. Although students might have a general understanding that they need to provide "evidence," these types of context-specific supports can help them understand what counts as evidence in that particular task. Specific prompts can also encourage students to connect the science content to their investigations and encourage greater meaning making (Puntambekar & Kolodner, 2005).

Research on argumentation and explanation from other disciplines has emphasized *generic* explanation scaffolds (e.g. reading, Reznitskaya & Anderson, 2002; debate, D. Kuhn & Udell, 2001, 2003). As we mentioned previously, 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. 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 effect of incorporating these different types of language into written curricular scaffolds. A previous study we conducted (McNeill, et al., 2006) compared two scaffold treatments, fading explanation scaffolds compared to keeping continuous explanation scaffolds in student materials. These scaffolds combined both context-specific components and generic components. The study showed that students who received scaffolds that faded over time acquired greater learning gains in terms of their ability to write 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 study by Lee and Songer (2004) in which they provided fifth grade students with context-specific written scaffolds. They found that fading prompts resulted in less student learning in terms of students' ability to formulate explanations from data. One possible explanation for the difference in these results is the context-specific versus generic nature of the prompts. The type of language in a written curricular prompt may influence whether it is more or less effective to fade that prompt over time. 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 a scientific explanation clear to students in order to facilitate their understanding of how to construct one. Making scientific thinking strategies explicit to students 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 content knowledge students needed to apply 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 the *Stuff* unit resulted in greater learning gains in terms of students' ability to write scientific explanations (McNeill et al., 2006).

In this research, we investigate whether the form of the scaffold, context-specific versus generic explanation, is related to student learning of both the science content as well as the scientific inquiry practice of explanation construction. Previous studies suggest that context-specific scaffolds may be more closely linked to students' understanding 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 (D. Kuhn & Udell, 2001).

Synergy: Interaction Between the Teacher and Curricular Scaffolds

Classrooms are complex systems and curricular scaffolds are not the only support influencing student learning. In distributed scaffolding, a collection of curriculum materials, technology, teacher instructional strategies, activity structures and peers work collectively to support learners (Puntambekar & Kolodner, 2005; Tabak, 2004). We are interested in the relationship between the two different written curricular scaffolds (context-specific vs. generic) and the various supports teachers provide students to successfully construct scientific explanations.

Tabak (2004) argues that distributed scaffolding can occur in three different patterns: differentiated, redundant and synergistic. *Differentiated support* is when there are multiple supports where each addresses a different need of the student or learning goal in the instruction. For example, Puntambekar and Kolodner (2005) discuss how in one design-based middle school unit around coastal erosion three different supports (design diaries, pin-up sessions, and whole class discussions) offer students different affordances for different learning goals. In this study, we are specifically interested in two types of support (teacher practices and curricular scaffolds) that support the same goal, scientific explanation. Consequently, we do not expect the pattern to emerge to be one of differentiated support.

Redundant supports are multiple supports that address the same need or learning goal, which can benefit students with different needs or who missed opportunities for support (Tabak, 2004). For example, a teacher may model how to graph data and look for trends and a software program may also provide examples of how to graph data and look for trends. The supports provide two different avenues for helping students with the same task. This can help students who do not understand or attend to one particular support or students who are struggling and need multiple forms of support. Redundant supports can be additive in that receiving two supports that address the same learning goal can result in greater learning than one support. If the curricular and teacher supports for scientific explanation are redundant supports, then students who receive more of these supports will have greater learning, but there will not be an interaction between the supports. For example, the effect of the generic written scaffold will be the same for all students regardless of the teacher support they receive for scientific explanation.

Finally, Tabak (2004) discusses the idea of *synergistic supports* in which there are multiple co-occurring and interacting supports in which the sum of the supports is not simply the addition of the individual supports. Rather the sum of the supports can be greater or less than the individual supports, because of the interaction between the supports. For example, a teacher may model how to graph data and look for trends using a piece of software. A piece of software may provide other types of support for creating graphs, such as providing students with feedback if they make an error when creating the axis. Providing feedback may influence what the student learns from the teacher modeling the example. Consequently, although both supports target the same goal of helping students create graphs, there can be an interaction between the two supports. Tabak provides the following rationale for the importance of synergistic supports:

> The rationale underlying this pattern is that some of the skills and practices that we are trying to foster integrate such a mélange of knowledge, skills, and values that few if any individual mediums or agents exist that would be able to support the development of these practices. It takes the concerted efforts of multiple scaffolds, some introducing a set of possible tools and actions, some communicating the utility of these actions, and others demonstrating how these

> actions can be coordinated to produce valued activity. Performance involves an integration of all of these aspects; therefore, learning through performance is facilitated by scaffolds or a system of scaffolds that simultaneously embody the full gamut of supports (p. 318).

The curricular scaffolds and teacher supports in this study may act as synergistic if there is an interaction between the supports. The combined effect of these two different types of support may not be additive, but rather entail a more complicated relationship where the effects of the supports are enmeshed. Tabak (2004) discusses that in order for synergy to be productive there needs to be coherence between the designed curriculum materials and the teacher's enactment of the materials. The teacher's enactment needs to align with the goals of the curriculum in terms of scientific explanation and with the support provided by the curricular scaffolds. By studying both the effect of the written curricular scaffolds and teacher practices, we are able to unpack whether there is a relationship between these different types of support, what that relationship looks like (e.g. redundant or synergistic), and how it influences student learning.

Method

Instructional Context

This study took place in the context of a two month middle school chemistry unit, *How can I make new stuff from old stuff?* or *Stuff* (McNeill, Harris, Heitzman, Lizotte, Sutherland & Krajcik, 2004). We designed the curriculum using a learning-goals-driven design model (Krajcik, McNeill & Reiser, in review) that uses key learning goals identified in the national standards (American Association for the Advancement of Science, 1993; National Research Council, 1996) to align curriculum materials and assessment measures. The *Stuff* unit focuses on three science content learning goals: substances and properties, chemical reactions, and conservation of mass. The unit engages the students in this content by contextualizing the science in everyday phenomena. For example, the unit begins with two unknown substances (fat and soap) and eventually the students explore whether or not you can make one of the substances (soap) from the other (fat). Besides fat and soap, students explore a variety of other phenomena as they develop richer understandings of the science content.

The unit also focuses on a variety of scientific inquiry practices, with a particular focus on scientific explanation. The curriculum includes thirteen different opportunities for students to write scientific explanations (see Table 1). During the first lesson in which students write scientific explanations (Lesson 6), the curriculum suggests that the students begin by writing a scientific explanation based on their own prior knowledge. The students' investigation sheet does not contain written scaffolds. After writing their explanations, the curriculum suggests that the teacher led a class discussion of scientific explanations that includes discussing a variety of examples of scientific explanations, connecting to students' prior knowledge, introducing the scientific explanation framework, comparing scientific explanation to everyday explanation, and modeling scientific explanations. Then students revise their scientific explanations based on the classroom conversation.

Table 1: Explanations Constructed 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.

Written Curricular Scaffolds

In order to explore the effect of the different written supports we created two scaffold treatments: context-specific and generic. We decided to fade the scaffolds over four stages since we found in our previous research that fading written scaffolds during the *Stuff* unit resulted in students constructing stronger explanations (McNeill, et al., 2006). Table 2 includes examples of the two different types of scaffolds during Stage I, which provide the most detailed support. The question for this example states, "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 explanation 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 2, 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 2: 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** (Write a statement that responds to the original problem.) **Evidence** (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.) **Reasoning** (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 provides students with content and task 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 as part of their reasoning for why their evidence supports their claim, "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 detail in the curricular scaffolds faded over four stages with the final stage, Stage IV, not including any curricular scaffolds on the student investigation sheets. Table 1 describes each lesson that included the curricular scaffolds and indicates the stage of the scaffold in that lesson.

Teacher Instructional Practices

Besides the curricular scaffolds, the curriculum suggests a number of instructional practices that the teachers can use during the curriculum to support student learning of scientific explanations. The curriculum materials included suggestions of five different instructional practices that teachers could use in their classrooms: defining scientific explanation, modeling scientific explanation, providing feedback, connecting to everyday discourse, and adapting the instruction based on students' prior knowledge. These strategies are discussed in more detail including both a rationale and examples in McNeill (2007).

Participants

The six teachers in the study came from six different schools in the Midwest. Table 3 provides the type of school and the number of students for each teacher.

Table 3: 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

Five of the six teachers taught in the same large urban area. Over ninety percent of the students in these five schools were African American and the majority were eligible for free or reduced lunch. The last teacher taught in an independent school in a large college town in which the majority of the students were Caucasian and from middle to upper-middle income families. The population of students in Ms. Nelson's school is clearly different from the other five schools. Yet we decided to keep Ms. Nelson in the study as a contrasting case to see if there were marked differences in her enactment of the curriculum or the effect of the curricular scaffolds on student learning of scientific explanation. Often in purposive sampling of cases, the atypical case provides a greater opportunity to learn about the phenomena of interest (Stake, 2000).

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). 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. 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.

We purposively selected teachers for this study with a range of backgrounds and previous experiences, because we were interested in naturally occurring contrasts (Shadish et al., 2002) in the teachers' enactment of the curriculum. For example, the teachers ranged in experience teaching science from four to twenty-seven years. Data collection around the teachers' enactments included videotaping of three lessons during the unit (Lessons 6, 8 and 13) that cut across the three different content areas. We also had the teachers complete two different questionnaires during their enactment one that focused on scientific explanation and the other that focused on their general enactment of the unit.

Data Analysis

Pre and posttests. Students completed identical pre and posttests that included fifteen multiple-choice items and three open-ended items where they were asked to write scientific explanations. The multiple-choice responses were scored and tallied for a maximum score of fifteen. In order to check the reliability we calculated Cronbach's alpha for the posttest multiple-choice items which was 0.777 suggesting that the items reliably measured students' understanding of the science content.

We developed rubrics for the three-opened ended scientific explanation items. These rubrics combined the conceptual adequacy of the students' arguments with a structural analysis (Sandoval & Millwood, 2005). An explanation that received the highest score was both scientifically accurate and appropriately justified the claim with evidence and reasoning. For each explanation, we scored separately students claim, evidence and reasoning each worth a possible of three points for a total of nine points across the three components. In other work, we describe our analysis of students' explanations in more detail including sample test items, rubrics and student responses (McNeill et al., 2006; McNeill & Krajcik, in press a; McNeill & Krajcik, in press b).

Each scientific explanation was scored by one rater. We then randomly sampled 20% of these open-ended test items and they were scored by a second independent rater. Inter-rater reliability was calculated by percent agreement. The inter-rater agreement was 98% for claim, 94% for evidence, and 98% for reasoning across the three explanation items. As a second reliability check, we calculated Cronbach's alpha for students' scores on the posttest scientific explanations which was 0.809 suggesting that the items reliably measured students' ability to write scientific explanations.

Teacher case studies. In order to analyze the classroom videotape, we developed a coding scheme for the teachers' instructional practices from both our theoretical framework and an iterative analysis of the data (Miles & Huberman, 1994). We coded the video for seven different instructional practices: modeling scientific explanations, defining scientific explanations, making that rationale behind scientific explanations explicit, connecting scientific explanations to everyday explanations, providing feedback to students, taking into account students' prior knowledge and experiences, and discussing the science content accurately and completely. Data from the analysis of the videotape and the two teacher questionnaires was used to develop case studies for the six teachers that provided a narrative that characterized the support each teacher provided their students for scientific explanation (Stake, 2000). This analysis and the case studies are presented in other work (McNeill, 2007). In this paper, we summarize the findings from the case studies in order to explore the relationship between the effect of the curricular scaffolds and teachers' instructional practices.

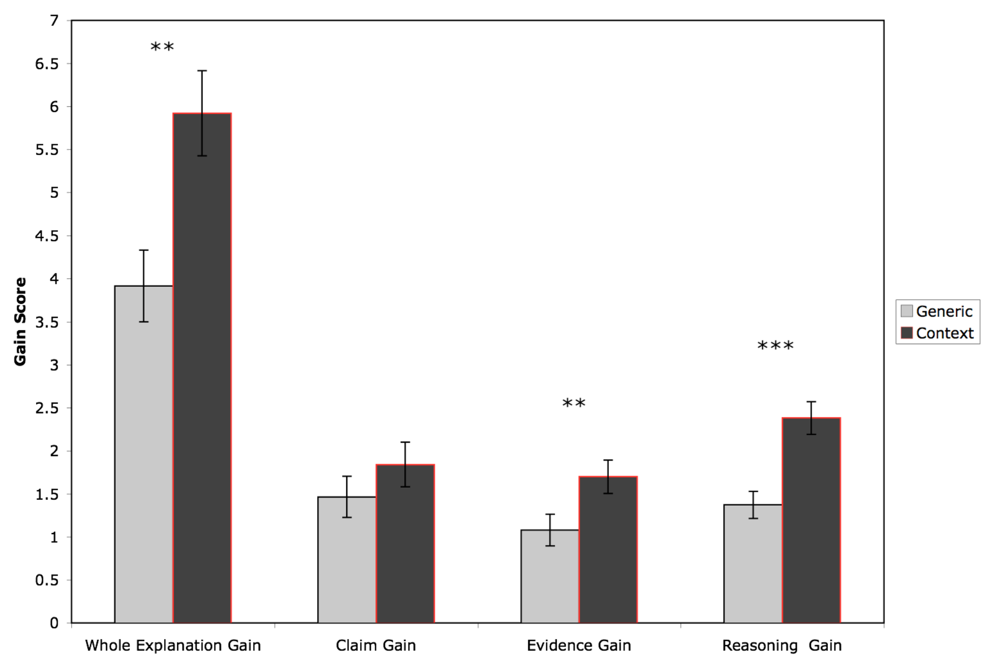
Results

In this section, we begin by describing the effect of the curricular scaffolds on student learning for all students combined. Then we briefly summarize the results from the case studies of the six teachers in terms of the instructional practices they used to support students in scientific explanation (McNeill, 2007). Finally, we examine the effect of the curricular scaffolds by teacher and discuss possible causes for this variation.

Influence of Curricular Scaffolds on Scientific Explanations

We investigated the effect of the two curricular scaffolds on student learning of scientific explanation as measured on the pre and posttests when students did not have other supports available to them. We examined whether the curricular scaffold treatment had a significant effect on student learning over the *Stuff* unit by using students' pre and posttest explanation scores to obtain gain scores for each student. 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 gain score as the outcome variable. Figure 1 displays the differences in the two treatment groups in terms of their gain scores for explanation, claim, evidence, and reasoning.

Figure 1: Effect of Scaffold Treatment on Scientific Explanations

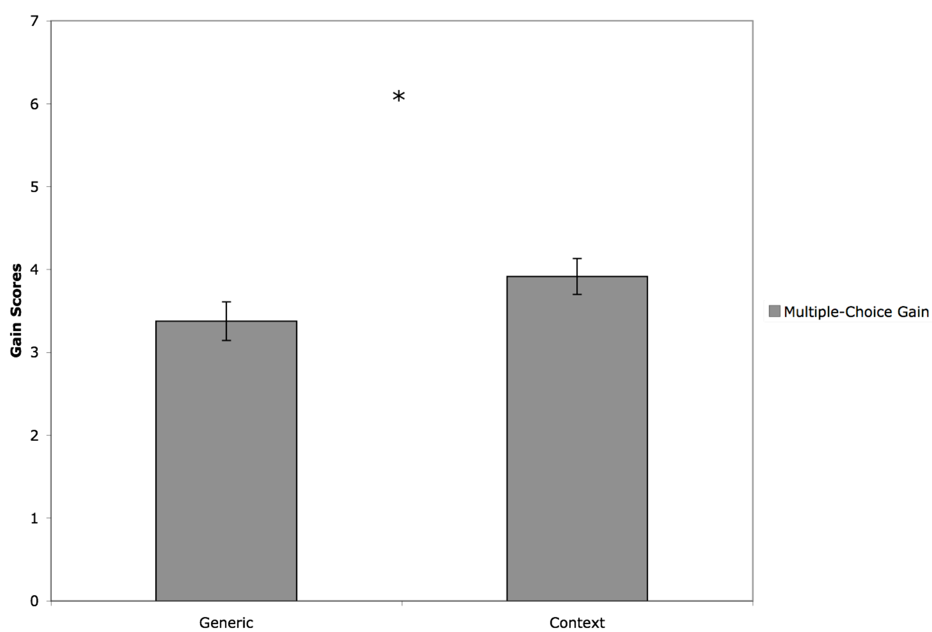


The effect of the curricular scaffold was significant for the whole explanation, evidence, and reasoning scores. In each case, the context-specific group (n = 163) demonstrated greater learning than the generic group (n=165) [1]. For the entire explanation, the context-specific group had larger gains after controlling for the covariate F (1, 324) = 11.84, $p < .01$. When we broke the analysis down by component, we found that for both evidence, F (1, 324) = 7.11, $p < .01$, and reasoning, F (1, 324) = 14.43, $p < .001$, the context-specific group had greater learning gains. These results 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.

Influence of Curricular Scaffolds on Science Content

We were also 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 ANCOVA on students' multiple-choice gain scores with the scaffold treatment (context-specific vs. generic) as the fixed factor and the pretest multiple-choice score as the covariate. Figure 2 shows the gain scores for both the generic and context-specific treatment groups.

Figure 2: Effect of Scaffold Treatment on Content Knowledge



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 greater student learning of the science content as measured by the multiple-choice items, F (1, 324) = 3.97, $p < .05$. Since the context-specific treatment resulted in greater student learning of the science content, this led to the question of whether the greater increase in the context-specific groups' scientific

[1] For all four ANCOVAs presented in this section, the interaction between the covariate and the scaffold treatment was not significant. The effect of the covariate was significant for claim and evidence, while it was not significant for the total explanation score or reasoning score.

explanation was a result of a greater understanding of explanation or if it was just a result of their greater understanding of the content knowledge. We revisit this question later.

Summary of Teacher Case Studies

In other work (McNeill, 2007), we describe in detail the enactments of the six teachers in terms of the support they provide their students for constructing scientific explanations. Here we summarize the key findings which may have influenced the variation that occurred in terms of the effect of the curricular scaffolds on student learning.

In terms of teachers' enactments of the curriculum, their use of the student investigation sheets that contained the curricular scaffolds varied. Ms. Marshall never had the students write their scientific explanations on the investigation sheet. Instead, she had them write their explanations on laptops, foldables or worksheets that she produced. Her students were never exposed to the curricular scaffolds. For the other five teachers, their students did write their scientific explanations on the investigation sheets with the curricular scaffolds

One pattern that emerged was the importance of how the teachers defined scientific explanation. Mr. Kaplan, Ms. Hill and Ms. Nelson all provided similar definitions compared to the curriculum materials (i.e. claim, evidence, and reasoning). Ms. Marshall and Ms. Foster used modified definitions of scientific explanation with their students. Instead of talking about scientific explanation consisting of claim, evidence, and reasoning, they discussed explanations as consisting of claim, definition, evidence, and therefore/conclusion. Rather then having students provide "reasoning", they had students provide a "definition." For example, in talking about the "definition", Ms. Marshall asked her class, "What word from my claim should I define?" Ms. Foster even explicitly pointed out to her students that what she was asking them to do was different than the curriculum. She told her students, "We ask for a definition. If you have noticed in our manual, in our book, they do not always ask us to do a definition… I just ask for a definition." Defining a word simplifies the reasoning component of scientific explanations. Neither teacher included the idea that the reasoning provided the logic or justification for the claim and evidence. Ms. Kittle discussed scientific explanation as consisting of claim, evidence, and reasoning, but provided a modified definition of reasoning. Before the *Stuff* unit, Ms. Kittle had introduced reasoning as a "definition", but then during the unit she revised how she talked about reasoning to more closely align with the curriculum materials. For example, she said to her students, "You can no longer tell me a definition of a word. You have to tell me how the definition relates to your claim and your evidence."

Not only did this modified framework influence how Ms. Marshall and Ms. Foster defined scientific explanation, but it also influenced how they modeled explanations in terms of the examples they provided and the features they pointed out to their students. The examples included a definition of a word such as, "A substance can be defined as that which has mass and occupies space", instead of discussing the idea that different substances have different properties, which was essential to forming an appropriate claim. Their definitions of scientific explanation also influenced the feedback they provided their students on their own explanations. For example, Ms. Foster would remind students to include CDEC in their explanations, which stood for claim, definition, evidence, and conclusion.

Mr. Kaplan, Ms. Hill and Ms. Nelson all defined scientific explanation in a similar manner to the curriculum materials and engaged in a variety of instructional practices that aligned with this learning goal. Mr. Kaplan and Ms. Hill's classroom instruction was similar in a variety of ways. They both worked in urban schools in which their students struggled with scientific explanations and they provided their students with a variety of explicit supports. Both Mr. Kaplan and Ms. Hill defined scientific explanations, provided and critiqued models for their students, built off of students' prior knowledge and spent considerable time providing students with feedback on their explanations in class. For example, in one lesson Mr. Kaplan had students share their explanations with the whole class. After one group of students shared their explanation, Mr. Kaplan focused the conversation around their reasoning. He said, "How could I complete this to make it a more complete reasoning? How can I link the evidence to the claim with the one principle relating to properties that we talked about? You have to think chemical reaction, properties, new substances? How can I kind of put all of those things together to hit this home?" These type of specific comments and questions about scientific explanations were prevalent in both Mr. Kaplan's and Ms. Hill's classrooms.

Similar to Mr. Kaplan and Ms. Hill, Ms. Nelson's class also included a focus on scientific explanation that aligned with the learning goals of the unit and she engaged in a variety of different instructional practices. One unique aspect about her classroom was that the students took greater control over the direction of the conversation. For example, Ms. Nelson showed the students an overhead with three examples of scientific explanations and asked the class to critique the examples. This led to an interesting conversation around the reasoning in the examples. Example three did not include a general scientific principle about properties in the reasoning. Yet one student, Molly, felt that this explanation was the strongest. Below is an excerpt from the full class discussion of Molly's idea in which the class tried to help her understand the weakness in the reasoning of explanation three.

> Ms. Nelson: Do you think it is ok that it does not have anything about properties? Specifically?
>
> Molly: Yeah, because it has the names of them.
>
> Paul: But, what if we do not know that they are properties?
>
> *A couple of students responding at the same time.*
>
> Paul: But the point is that to actually tell someone about it, and that is –
>
> David: Right. You are suppose to be able to have some average Joe come up here and be able to understand what you are talking about.

The discourse in science classrooms has traditionally consisted of an IRE pattern in which the teacher initiates a student, the student responds, and the teacher evaluates the student response (Lemke, 1990). During the conversation about these three examples, Ms. Nelson only asked two questions and the rest of the conversation was driven by the students' critique of the explanations and responses to each other. The students took greater control and ownership over the conversation. Their questions and comments illustrate their strong understanding of the scientific explanation framework and their ability to apply that framework to a concrete example.

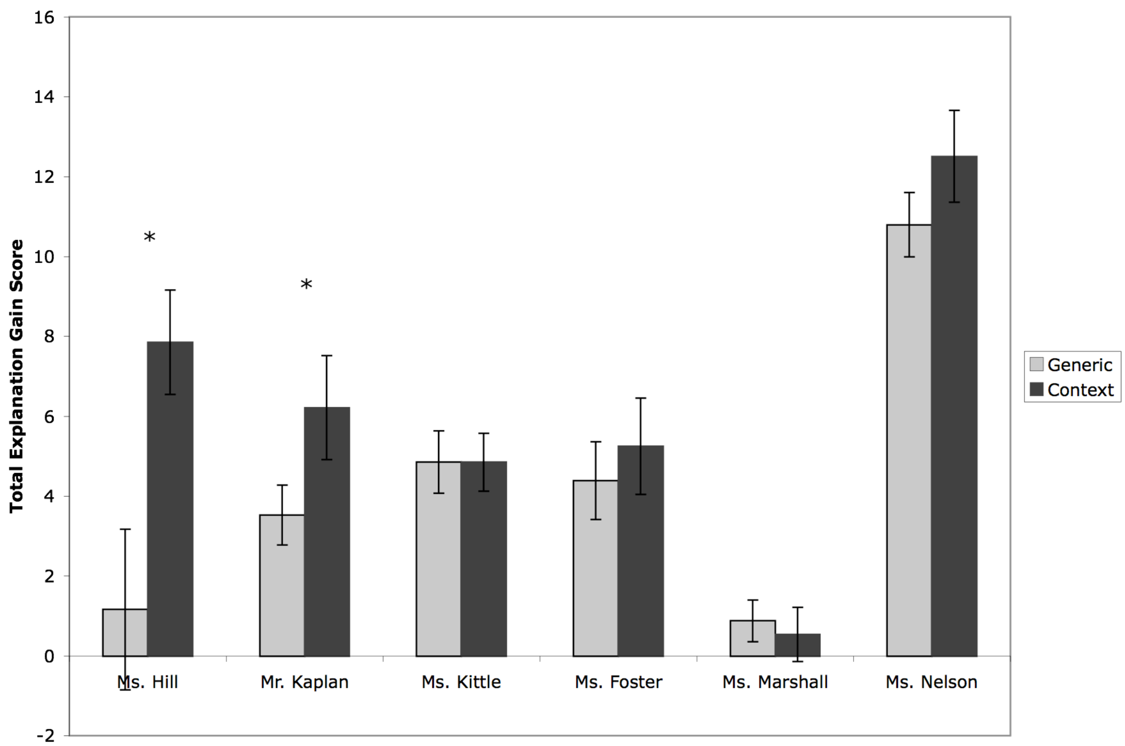
Overall, the key patterns that emerged from the case studies of the teacher practices focused on the way they defined scientific explanation, their alignment with the goals in the curriculum materials, and the discourse patterns in their classrooms.

Relationship between Teacher and Curricular Scaffolds

We split the data file by teacher and then ran 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 gain score as the outcome variable separately for each teacher to determine if there was a significant difference in the effect of the written curricular scaffolds by teacher. We completed this analysis five times, for the whole explanation, claim score, evidence score, reasoning score and multiple-choice score. For the claim score, consistent with the combined data set, there was not a significant scaffold effect for any of the six teachers. Consequently, we do not present those results. The results from the other four analyses are presented below.

For the entire scientific explanation score, the curricular scaffolds significantly affected student learning after controlling for any differences in where students began on the pretest for two teachers, Mr. Kaplan, $F\ (1, 47) = 5.06$, $p < .05$, and Ms. Hill, $F\ (1, 19) = 4.48$, $p < .05$. The context-specific group demonstrated greater student learning for both Mr. Kaplan's and Ms. Hill's students[2]. Figure 3 displays the gain scores for explanation for each teacher by scaffold treatment.

Figure 3: Effect of Scaffold Treatment for Explanation By Teacher



When the data were broken down by teacher, there was not a significant curricular scaffold effect for the other four teachers in terms of the complete explanation score. One type of scaffold was not more effective in promoting student learning of how to write a scientific explanation.

For evidence, the only teacher where there was a significant curricular effect on student learning after controlling for the covariate was Ms. Hill, $F\ (1, 19) = 5.75$, $p < .05$[3]. Figure 4 shows the evidence gain scores by teacher for the two curricular scaffold treatments.

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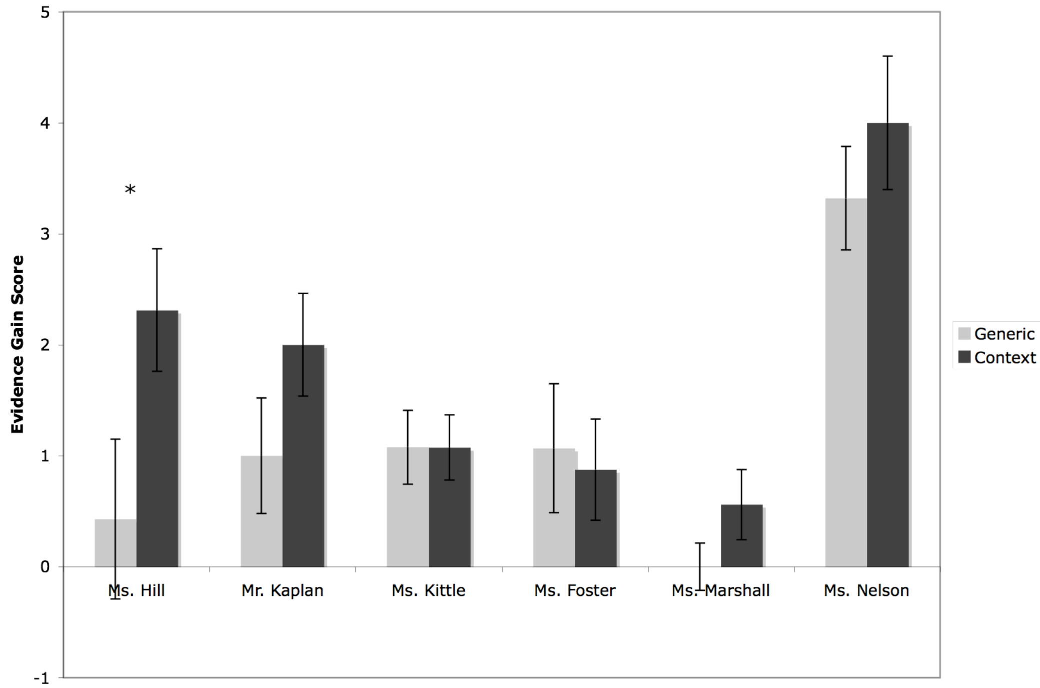
[2] For both Mr. Kaplan and Ms. Hill the effect of the covariate and the interaction between the covariate and the scaffold treatment was not significant.

[3] For Ms. Hill's students for evidence the covariate was not significant and the interaction between the covariate and the scaffold treatment was not significant.

Figure 4: Effect of Scaffold Treatment for Evidence By Teacher

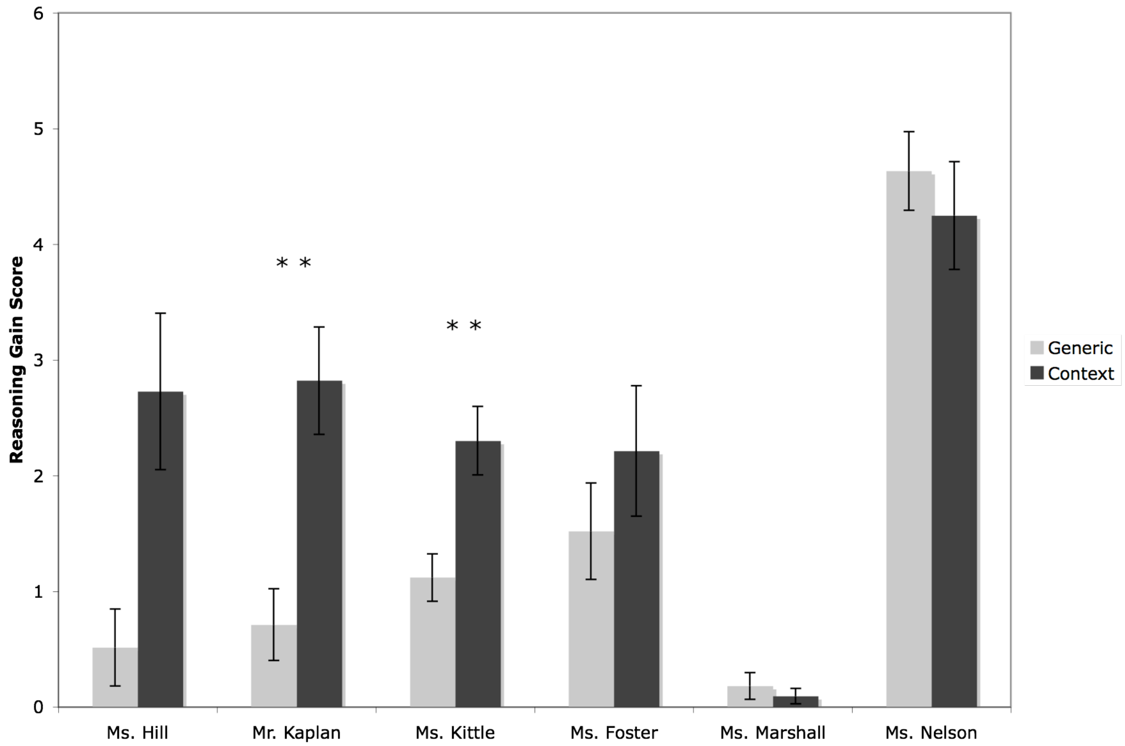


Although across the total explanation score, Mr. Kaplan's students in the context-specific group had greater learning gains, there was not a significant effect specifically for evidence. The curricular scaffolds only had an effect on Ms. Hill's students' ability to include evidence in their explanations.

Finally, we examined whether there was a curricular scaffold effect for reasoning by teacher. For both Mr. Kaplan, $F(1, 47) = 10.95$, $p < .01$, and Ms. Kittle, $F(1, 90) = 7.60$, $p < .01$, there was a significant scaffold effect for student learning of reasoning[4]. Figure 5 displays the gain scores for reasoning for each teacher by curricular scaffold treatment.

[4] For both Mr. Kaplan and Ms. Kittle the effect of the covariate and the interaction between the covariate and the scaffold treatment were not significant.

Figure 5: Effect of Scaffold Treatment for Reasoning By Teacher

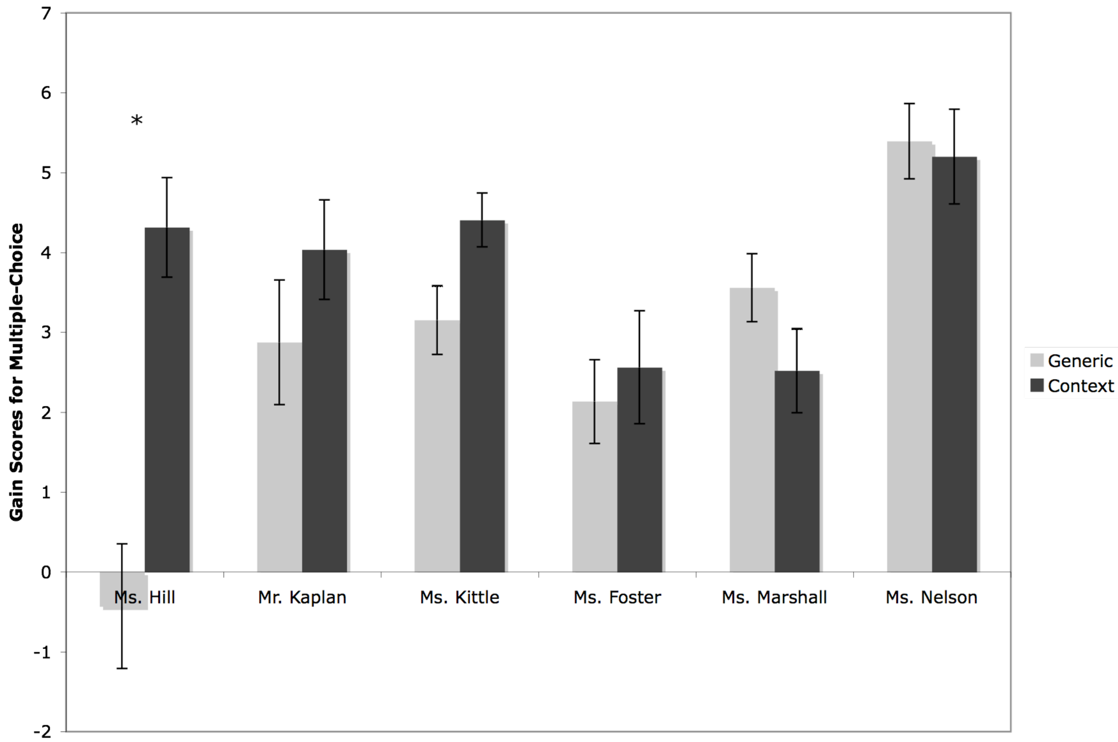


Although there was a significant effect for Ms. Hill's students for the total explanation score and evidence, there was not a significant effect for reasoning. For Ms. Kittle, there was not an overall effect on students' explanation scores, yet specifically for reasoning the context-specific scaffolds resulted in greater student learning.

Finally, we examined whether the curricular scaffolds influenced student learning of the science content as measured by the multiple-choice items by teacher. For the science content, there was a significant effect on students' multiple-choice gain scores after controlling for any differences in the pretest for one teacher, Ms. Hill, F (1, 19) = 5.71, $p < .05$[5]. Figure 6 displays the gain scores for the multiple-choice items by teacher.

[5] For Ms. Hill's students for the multiple-choice scores the covariate was significant, but the interaction between the covariate and the scaffold treatment were not significant.

Figure 6: Effect of Scaffold Treatment for Content By Teacher



Surprisingly, Ms. Hill's students who received the generic scaffold treatment did not significantly improve over the course of the unit in terms of their scores on the multiple-choice items. For the other five teachers, there was not a significant difference in the students' content knowledge for the two curricular scaffold treatments. This is particularly interesting for Mr. Kaplan and Ms. Kittle where there were significant differences in terms of the scaffold treatments for aspects of their students' learning of scientific explanation. This suggests that the differences in learning of scientific explanation were not just the result of increased learning of the science content, but rather an increased understanding of how to write a scientific explanation for these particular content areas.

Summary. Overall, there was a significant interaction between the effect of the scaffold treatment and the teachers' enactments of the *Stuff* unit. For three of the teachers, Mr. Foster, Ms. Marshall, and Ms. Nelson, the curricular scaffolds did not have differential effects on student learning of either scientific explanation or the science content. Ms. Hill's students who received the context-specific scaffold treatment had greater learning for the overall explanation, evidence, and multiple-choice scores. Mr. Kaplan's students who received the context-specific treatment had greater learning for the overall explanation and reasoning scores. Finally, Ms. Kittle's students who received the context-specific scaffolds had greater learning for the reasoning scores. The fact that context-specific scaffolds influenced both Mr. Kaplan's and Ms. Kittle's students' learning of scientific explanation, but not the science content suggests that the increased performance in terms of the ability to write scientific explanation was not just the result of a stronger understanding of the content. Rather the context-specific scaffolds helped students learn how to write stronger scientific explanations in this particular content area.

Relationship between Teacher Practices and Curricular Scaffolds

Based on their enactments of the *Stuff* unit, it is reasonable that there was not an effect of the curricular scaffolds for Ms. Marshall's, Ms. Nelson's or Ms. Foster's students. In Ms. Marshall's case, as we mentioned previously, her students were not exposed to the treatment. She chose not to have her students write their explanations in their student books. Consequently, the students did not have that written curricular support to help them with their writing. If we had found a scaffold treatment effect in Ms. Marshall's classes, we would have been concerned about the validity of the design of the study.

Ms. Foster used a modified version of the definition of scientific explanation used in the curriculum materials and specifically told her class that she wanted them to write their explanations based on what she asked for and not what the curricular scaffolds requested. Because she distinguished and prioritized her own instruction, it makes sense that the curricular scaffolds would not influence student learning. Students would not necessarily pay as close attention to the support provided to them in terms of scientific explanation in their investigation books. Rather, Ms. Foster's support was more important than the curricular support in her students' writing of scientific explanations.

For Ms. Nelson's class, the written curricular scaffolds also did not have an effect on student learning even though her students were exposed to the written curricular scaffolds. One possible reason why the curricular scaffolds did not influence her students' learning is because her students developed a strong understanding of scientific explanation during the unit as indicated by their role in classroom discussions about scientific explanation and their strong written scientific explanations. Since Ms. Nelson's students developed such a strong understanding of scientific explanation seemingly early in the unit, the curricular scaffolds may not have impacted student learning. Rather the students received sufficient support from their teacher and from each other that the curricular scaffolds became unnecessary.

Finally, there is the question of why the context-specific scaffolds were more effective than the generic scaffolds for Ms. Hill's, Mr. Kaplan's and Ms. Kittle's students for some aspects of scientific explanation. In all three cases, the students of these teachers started the unit with low achievement in terms of scientific explanation (McNeill, 2007). Consequently, there was a need for support in engaging in this complex inquiry practice. The interaction between the teachers' enactment and the curricular scaffolds effect is not the result of one particular instructional practice that all of the teachers used in their classrooms. Rather, it is the system of supports they used in their classroom that provided the students with the general framework of scientific explanation and complemented the support provided by the context-specific scaffolds. All three teachers talked about scientific explanation as claim, evidence, and reasoning and frequently used this general language in their classrooms. They also all provided their students with a variety of instructional support. In the discussion, we describe in more detail why these teacher instructional practices may have been "synergistic" (Tabak, 2004), with the context specific curricular scaffolds.

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 (Duschl et al., 2006; Gotwals & Songer, 2006; 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 and whether or not the effect varied based on the teacher's use of the curriculum materials.

The Effect of the Context-Specific and Generic Scaffolds

The context-specific scaffolds resulted in greater student learning in terms of students' ability to write scientific explanation, particularly in terms of evidence and reasoning. Students' performance on the posttest reflected their individual understanding that they gained from the curricular and teacher supports in the classroom environment and from writing explanations in that environment. When we examined students' pre to posttest gain scores for scientific explanations, students who received the context-specific scaffolds demonstrated greater student learning in terms of their ability to write scientific explanations independently. They learned more about writing scientific explanations from the context-specific scaffolds than their peers did from the generic explanation scaffolds.

We also examined students' content knowledge to investigate whether this scaffold effect was the result of a stronger understanding of how to construct scientific explanations or simply a stronger understanding of the science content. The context-specific group developed a stronger understanding of the content knowledge over the course of the unit compared to the generic group. Consequently, across all six teachers the context-specific written scaffolds resulted in greater student learning of both scientific explanation and the science content. As we will discuss later, this effect actually varied across teachers. The context-specific scaffolds resulted in greater student learning of scientific explanation and content for only some of the teachers' students. But first we discuss why the scaffold effect may have occurred at all. Specifically we address 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 at promoting student learning of scientific explanation?

Possible Causes of the Effect of the Context-Specific Scaffolds

Reflecting back on the written curricular scaffolds (see Table 2), the context-specific scaffolds did support students in the key science learning goals for the unit. For example, the scaffold provided in Table 2 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 in general of the science content. Developing a deeper understanding of this idea would help students respond correctly to the multiple-choice items on the test. 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 for supporting students in writing scientific explanations. Similar to our findings, previous research has found that context-specific scaffolds can help students construct explanations. For example, Sandoval (2003) found that providing students with prompts that focused on how to apply the concept of natural selection to write scientific explanations supported students in constructing strong explanations. Lee and Songer (2004) also found that providing students with context-specific scaffolds within an inquiry-oriented curriculum resulted in students writing explanations where they justified their claims with evidence. Yet other previous research (Reznitskaya & Anderson, 2002; D. Kuhn & Udell, 2001, 2003) found that generic prompts can result in greater student learning of explanation and argumentation.

One possible reason for why the context-specific supports were more effective in this study is because the students developed an understanding of the general explanation framework from classroom support; consequently, the generic explanation scaffolds became "redundant" (Tabak, 2004). Redundant scaffolds are when two or more supports address the same need or learning goal. Besides the written curricular scaffolds, the teachers who enacted the unit provided students with support around constructing scientific explanations that helped students learn the general framework. Furthermore, the general framework of claim, evidence, and reasoning remained constant throughout the curriculum unit. Consequently, the support from the teachers may have been sufficient in helping students understand this general framework. Many researchers (Duschl et al., 2006; D. Kuhn, Schauble & Garcia-Mila; Metz, 2000; Schunn & Anderson, 1999; Zimmerman, 2000) argue that both a domain-general understanding of a scientific inquiry practice and a domain-specific understanding of the science concepts are important for students' successful completion of a complex inquiry task. The teacher instructional support may have been sufficient to help students develop a domain-general understanding of the framework for scientific explanation.

Although the general framework for scientific explanation remained the same throughout, the context of each scientific explanation changed and the context-specific scaffold for each task changed. Because the tasks and the explanations constantly changed, this may have created a greater need for the context-specific supports, which is why they promoted greater student learning. As Schunn and Anderson (1999) argue "…it may be that skills that logically should generalize do not transfer because they require supporting domain-specific knowledge" (p. 341). Perhaps it was more difficult for students to apply the scientific explanation framework to new tasks than to develop a general understanding of the scientific explanation framework. The context-specific scaffolds may have helped students develop a stronger understanding of the domain-specific or content knowledge as well as how to apply that knowledge to write a scientific explanation for the particular task.

In terms of the effectiveness of the context-specific scaffolds, the question also exists whether these scaffolds just promoted students' understanding of the content or if they also promoted students' understanding of how to construct scientific explanations. For two teachers' students, the context-specific treatment resulted in greater student learning gains for students' written scientific explanations, but the two curricular scaffolds did not have differential effects on their students' understanding of the content as measured by the multiple-choice items. This provides some evidence that the context-specific scaffolds were providing students with support specifically about how to apply the science content to write scientific explanations. The context-specific scaffolds may have helped students understand what counted as evidence or what counted as reasoning for a particular task. This suggests that the context-specific supports were not just helping students develop a domain-specific understanding of the science concepts (e.g. what is a chemical reaction), but rather students developed a stronger understanding of how to apply those science concepts to write a scientific explanation (e.g. what evidence should be used to prove that a chemical reaction occurred). Both Mr. Kaplan and Ms. Kittle provided their students with support for the general scientific explanation in terms of claim, evidence, and reasoning. The context-specific scaffolds then helped students understand what they should include for the evidence and reasoning for a particular task.

This supports the idea that domain-general knowledge and domain-specific knowledge are not a dichotomy (Perkins & Salomon, 1989; Schunn & Anderson, 1999). The type of knowledge students were developing in this case lies between the two extremes, because it focuses on how to apply the science concepts to a scientific inquiry practice. The context-specific scaffolds supported students in understanding how to use the general scientific explanation framework of claim, evidence, and reasoning. The scaffolds may have helped students understand what science content to apply to write a more convincing scientific explanation.

In this study, our methods do not allow us to fully evaluate the differential effect on students' understanding of the general scientific explanation framework, the science content, or on how to apply the scientific explanation framework to a particular context. Recent research on psychometric models (Gotwals & Songer, 2006; Wilson, 2005) is helping to develop more effective assessment systems to tease apart students' understanding of science content and scientific inquiry. Furthermore, 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. This type of distal measure may have resulted in the generic scaffolds being more effective. Future studies that take advantage of different assessment systems will provide further insight into how to best support students in these complex inquiry tasks that utilize a variety of types of knowledge.

Curricular Scaffolds versus Cognitive Tools

The results from this study, in combination with previous research, raise the question of whether the term "scaffold" is inappropriate for the context-specific support that we provided students. In 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 always remain a part of the instructional setting to support student learning. In our design of the 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 students were able to internalize the general explanation framework. This raises the question of whether the context-specific supports would have been more effective if they remained continuous throughout the eight-week chemistry unit and consequently more aptly referred to as cognitive tools.

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 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. If a student is unable to complete a task independently, it may be more productive for the support to remain.

The results from this study alone are not sufficient to know if the context-specific supports would be most effective as scaffolds that fade over the *Stuff* unit, scaffolds that fade over a longer period of time, or cognitive tools that remain constant over time. In deciding whether a curricular support should fade or stay constant over time, this study suggests that it may be important to consider if the support is unique in every context. If the support changes with the context, then students may benefit more if the support remains over time. If the support has common features that repeat in new context, then it may be more effective to fade those scaffolds over time. Future research is needed to empirically investigate this idea and provide further recommendations on how to most effectively design instructional supports.

Distributed Scaffolding and Synergy

A scaffolded tool can influence classroom practice by acting as a social tool to achieve common meaning during student discourse (Roschelle, 1992). For example, including the scientific explanation framework as written scaffolds in the curriculum materials may help facilitate classroom discourse that prioritizes using evidence and reasoning to support knowledge claims in science. Yet the role of the teacher is also essential to the use of a scaffolded tool (Pea, 2004). Regardless of the intent of the curriculum designers, the actual impact of the curriculum materials is greatly influenced by this interaction between the teacher, students, and other resources in the classroom.

One way to describe this complex system of supports is through "distributed scaffolding." Distributed scaffolding is when a collection of curriculum materials, teacher instructional strategies, activity structures and peers work collectively to support learners (Puntambekar & Kolodner, 2005; Tabak, 2004). Tabak (2004) illustrated how the teacher and software scaffolds can work in concert to promote students' ability to reason about a complex task around natural selection. In this study, we also found that there was an important interaction between the role of the teacher and the effect of the two different curricular supports. Tabak (2004) discusses how distributed scaffolding can occur in three different patterns: differentiated, redundant and synergistic.

Differentiated support is when different supports address different learning goals. Since the focus of this study was on curricular scaffolds and teachers' practices that supported one learning goal, scientific explanation, we did not find differentiated support. There were other possible differentiated supports within the curriculum enactments, such as both curricular and teacher support for modeling compared to scientific explanation, but we did not investigate these other supports in this study.

Redundant scaffolds are those that address the same need or learning goal as the other supports. They potentially provide students with two different avenues for completing the same task. Tabak (2004) discusses the possibility of these supports being additive where combined they provide support equal to the sum of the individual supports. In this study, the generic written curricular scaffolds were redundant with the teacher instructional supports in that they appeared to be providing similar support for the general framework, yet that support did not seem to be additive. The generic explanation scaffolds basically defined scientific explanation and discussed each of the three components. They focused on domain-general expertise in science in that they supported middle school students' understanding of a general scientific explanation framework that students could use across different domains. If the teacher was providing this support to his or her students, then the generic scaffolds may have become redundant. In the cases of Mr. Kaplan, Ms. Hill, Ms. Kittle, and Ms. Nelson, the teachers provided students with support for the general framework of scientific explanation. All four teachers defined scientific explanation as claim, evidence, and reasoning and used this general language for scientific explanation frequently in their classrooms. Consequently, for all four teachers, the generic written scaffolds were redundant with the instructional support they were providing in the classroom, yet there was not an additive benefit of the different supports. This example extends Tabak's (2004) discussion of redundant support, which suggested that redundancy was a positive characteristic of a learning environment, because it catered to the multiple needs of different students. In this example, the redundancy did not provide an added benefit which is another possible outcome of redundant supports.

For Ms. Nelson's students the context-specific written scaffolds were also redundant or they were unnecessary supports. For her students, neither written curricular scaffold was more effective. This may be because Ms. Nelson already provided this type of context-specific support to her students. For example, she provided explicit written formative feedback to her students on all explanations they wrote in class (McNeill, 2007). This provided students with context-specific feedback on how to apply the general scientific explanation to effectively write an explanation for a particular task. Another possibility is that the curricular scaffolds may not have influenced student learning because of her students' strong understanding of scientific explanation. Scaffolds allow students to achieve a higher level of understanding within their zone of proximal development (Stone, 1993). Perhaps these curricular scaffolds were below her students' zone of proximal development so that they did not provide the students with support. At the beginning of the unit, Ms. Nelson's students had higher performance for their scientific explanations than the other students. Furthermore, their discourse during the unit reflected a strong understanding of the scientific explanation framework and how to apply it to a particular task. Consequently, neither scaffold may have been effective at promoting student learning of scientific explanation.

Finally, Tabak (2004) defines synergistic supports as when there are multiple co-occurring and interacting supports where the sum of the supports is greater than the individual supports. Mr. Kaplan's, Ms. Hill's and Ms. Kittle's instructional supports were synergistic with the context-specific written scaffolds in that they complemented the curricular scaffolds and resulted in greater student learning in terms of the ability to write scientific explanations. This increased learning of the students who received the context-specific support may be because the scaffolds helped the students learn how to apply the general explanation framework to a specific context, such as understanding what counted as evidence for a particular task. This may have helped students develop knowledge of how to apply the general explanation framework.

This leads to the question of why neither scaffold was more effective in Ms. Marshall's and Ms. Foster's classrooms. In order for different supports to act synergistically, there should be thematic continuity between them (Tabak, 2004). Tabak argues, "…for productive synergy to occur…different materials need to share semiotic features, and these features need to be consistent not only with the designers' but with the teacher's conception of the task, goals, and discipline" (p. 329). In the cases of Ms. Marshall and Ms. Foster there was in fact a discontinuity between the initial intent of the designers and the resulting enactment of the explanation framework in their classrooms. One of the essential features of a scaffold is a shared understanding of the goal of the activity (Puntambekar & Kolodner, 2005). The modified definitions of scientific explanation used by Ms. Marshall and Ms. Foster suggest that they did not share the same goal for scientific explanation as intended by the curriculum materials. In Ms. Foster's case, she specifically devalued the role of the written scaffolds with her students by telling them to follow her definition of scientific explanation and not the curriculum materials. In Ms Marshall's case, she simply did not have her students use the written curricular scaffolds. Without this congruency between the teacher instructional support and the curricular scaffolds, there was not a synergistic relationship to produce a more robust system of support for student learning of how to write scientific explanations.

Implications

Perkins and Salomon (1989) argued over fifteen years ago for the importance of both domain-general and domain-specific knowledge. They described the swings in the educational field from a focus on more general strategic knowledge to more domain-specific knowledge. They forecasted a future research agenda that brought together a variety of knowledge and instructional support. The results from this study suggest the importance of these different types of knowledge and support when engaging students in complex inquiry practices. Writing a scientific explanation involves a variety of knowledge including a domain-general understanding of scientific explanation (e.g. that it includes claim, evidence, and reasoning), a domain-specific understanding of the content (e.g. what is a chemical reaction), and knowledge about how to apply the general framework to a particular science task (e.g. different properties such as density and melting point count as evidence that a chemical reaction occurred). The context-specific curricular scaffolds were more successful in supporting students in this complex task, but they were only more effective in teachers' enactments that included a focus on explanation as a more general scientific inquiry practice. The system of supports in these classrooms reflects what Perkins and Salomon called for in terms of an "intimate intermingling of generality and context-specificity in instruction" (p. 24). The combination of support from both the teacher and the curriculum materials provided assistance for both the general scientific explanation framework and how to apply that framework to a particular context.

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 emphasizes the importance of considering the interaction between teacher instructional practices and the effects of scaffolds. Scaffolded tools may not necessarily have the same effect in all classrooms. In order to productively use scaffolded curriculum materials, there needs to be a synergistic relationship between the learning goals and instructional practices of the teacher and the learning goals and supports in the curriculum materials.

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