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# Designing Instructional Materials to Support Students' in Writing Scientific Explanations: Using Evidence and Reasoning Across the Middle School Years

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Explaining phenomena is a central aspect of what it means to do science. Scientists construct explanation to make sense of how or why a phenomenon occurred. In constructing explanations scientists produce arguments by defending or supporting knowledge claims through evidence, warrants and backing (Toulmin, 1958). As such, the national science education standards (National Research Council,1996; American Association for the Advancement of Science, 1993) call for students to engage in constructing scientific explanations. The national science education standards view the construction of explanations as essential for scientific literacy because of the central roles of using evidence and explaining phenomena in science. In fact, the essential features of inquiry described in the National Science Education Standards, focus on explanation. The five essential features state that learners: 1) engage in scientifically oriented questions 2) give priority to evidence in responding to questions, 3) formulate explanation from evidence, 4) connects explanations to scientific knowledge and 5) communicate and justify explanations (National Research Council, 2000).

A recent National Academies workshop identified five critical 21st century skills: 1) adaptability, 2) complex communication/social skills, 3) non-routine problem solving, 4) self-management/self-development, and 5) systems thinking (National Research Council, 2008). Because constructing explanation engages students in problem solving, using evidence, and communicating, it can be considered an important process of supporting students in building 21st century skills. In constructing models and writing scientific explanations students need to consider if all evidence is used. The research shows that most individuals do not consider all evidence, particularly if the evidence does not support their point of view (Sandoval & Millwood, 2005). Taking into consideration all evidence is a key aspect of adaptability and complex problem solving. As such, constructing explanations are essential not only for scientists, but all individuals because of the central role that evidence and reasoning plays in the construction of explanation. Individuals need to evaluate scientific data provided to them in written form from such sources as the web, newspapers and magazines as well spoken through television and radio. Citizens need to be able to evaluate explanations to determine whether the claims being made based on the data and reasoning are indeed valid. This type of data evaluation, like other scientific inquiry practices, is dependent both on a general understanding of how to evaluate data as well as an understanding of the science content. Research in the field also indicates that engaging students in constructing claims justified by evidence and reasoning can also help them improve their understanding of content knowledge (Zohar & Nemer, 2002).

## *Purpose*

In this paper, we focus on how middle school students can be supported to construct evidence-based scientific explanations throughout the middle grade years. We explore the following questions central to the use of explanations in classrooms: How can instructional materials be designed to support students in scientific explanations? How can an explicit framework increase in complexity across time to support students in developing more complex capabilities to construct scientific explanations? How do students' explanations change across time when supported by a framework?

## *Student Difficulties Constructing Explanations*

Unfortunately, although scientific explanation is critical for scientific literacy, prior research in science classrooms suggests that students have difficulty constructing high-quality scientific explanations where they articulate and defend their claims with evidence (Sadler, 2004). Instead, students will draw on data that do not support their claim or will rely on their personal views instead of evidence to draw conclusions and support claims (Hogan & Maglienti, 2001). Worse yet, students will accept claims without asking what evidence supports the claim as researchers have shown that during classroom discourse, discussions tend to be dominated by claims with limited justification (Jiménez-Aleixandre, Rodríguez & Duschl, 2000). Students also have difficulty providing the backing and warrants needed to support claims (Bell & Linn, 2000). Our previous work aligns with the findings of other researchers. We found that middle school students' had difficulty with providing evidence and using reasoning when constructing explanations when they had not been provided with support around this complex practice (McNeill, Lizotte, Krajcik & Marx, 2006; McNeill and Krajcik, 2008).

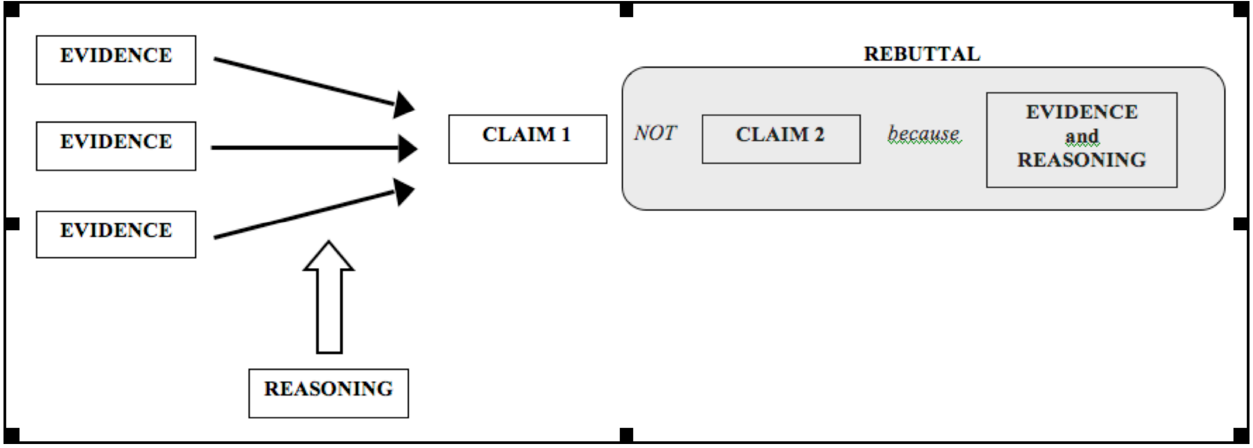
Perhaps one major reason for students' difficulty in constructing evidence-based explanations, from an instructional perspective, is that students are seldom supported in this scientific practice. One of our goals is to create a framework that can support both teachers and learners in this process and as such make a complex task accessible. One of our aims is to help students develop a rich understanding of how claims are supported and critiqued in science to use not only in their science classrooms, but also in their everyday experiences such as evaluating claims found in various popular media.

## *Instructional Supports for Scientific Explanations*

In our work with elementary, middle and high school students, we have used a framework to support students in constructing evidence-based scientific explanations. Through the use of student instructional materials and educative curriculum materials for teachers, we provide both teachers and students with a framework to make the implicit model of explanation, explicit to them. Our framework for scientific explanation is an adaptation from Toulmin's (1958) model of argumentation and builds off previous science educators' research on students' construction of scientific explanations and arguments (Clark & Sampson, 2007; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Lee & Songer, 2004; Osborne, Erduran & Simon, 2004; Zembal-Saul, et al., 2002). However, because our work focuses on classrooms, we chose to refer to this scientific practice as scientific explanation instead of argument to align with the language of the national standards.

Our explanation framework includes three components: a claim (similar to Toulmin's claim), evidence (similar to Toulmin's data), and reasoning (a combination of Toulmin's warrants and backing). The claim makes an assertion or conclusion that addresses the original question. The evidence supports the student's claim using scientific data. This data can come from an investigation that students complete 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. The reasoning is a justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate scientific principles. As students advance in the understanding of constructing scientific explanation, we introduce them to a fourth component – rebuttal. Rebuttal describes alternative explanations and provides counter evidence and reasoning for why the alternative is not appropriate. Figure 1 illustrates how the rebuttal connects to the other three components of claim, evidence and reasoning. This figure illustrates how the evidence supports the claim and the reasoning provides a justification for that link between the claim and evidence and how the rebuttal considers and rules out alternative explanations for a scientific phenomenon.

Figure 1: *Claim, Evidence, Reasoning and Rebuttal (from McNeill & Krajcik, in preparation)*



### *Value of the Explanation Framework*

Although the framework presents a simple model of supporting learners in the process of constructing scientific explanations, it is accessible to both teachers and learners in elementary, middle and high school that allows them to engage in an important practice of science. We have conducted a number of studies that has shown the value of this approach to promoting student learning of both science content and the ability to construct scientific explanation (Krajcik, McNeill & Reiser, 2008; McNeill, 2009; McNeill & Krajcik, in press; McNeill & Krajcik, 2008, McNeill & Krajcik, 2007; McNeill, Lizotte, Krajcik, & Marx, 2006). One important lesson we have learned is that if we want to have an impact not only on the literature but also on practice, we need to find ways that communicate with classroom teachers. Requests to publish our ideas in manuscripts directed at practice (McNeill & Krajcik, 2008a, 2008b; Sutherland, McNeill, Krajcik, & Colson, 2006) and to present our ideas at teacher conferences (Krajcik & McNeill, 2007; Krajcik & McNeill, 2006; Krajcik & McNeill, 2005; Krajcik, McNeill & Novak, 2008; McNeill & Krajcik, 2009) suggests that the framework is an accessible, usable and potentially scalable way to engage teachers in thinking about this scientific practice and supporting their own students in constructing scientific explanations. Teachers have approached us and expressed their gratitude for the framework. For example at the 2009 NSTA Annual meeting, several teachers approached us. One teacher stated the CER has spread throughout her school. At first we had no idea what she was talking about, but then realized that "CER" stands for Claim, Evidence and Reasoning. Although this is only anecdotal evidence and not strong support for our claim about the scalability of this approach, it points in the direction of creating instructional frameworks or models that can impact schools.

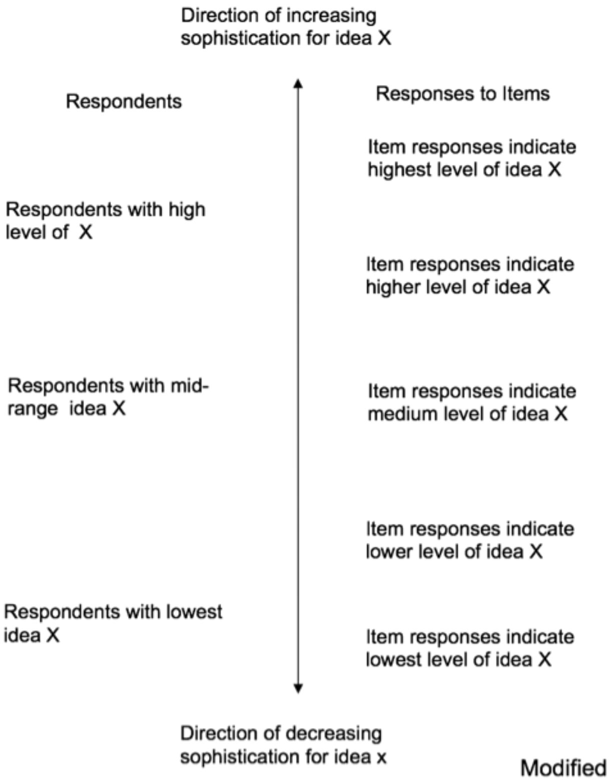
Our research (McNeill & Krajcik, 2009; McNeill and Krajcik, 2008; McNeill 2009) has shown that teachers also have to provide other instructional supports in the classroom for students to develop an understanding of scientific explanation these include: 1) making the framework explicit, 2) discussing the rationale behind explanation, 3) modeling the construction of explanations, 4) discussing similarities and differences with everyday explanations 5) providing multiple opportunities to construct explanations, 6) giving opportunities for students to critique each others explanations and 7) providing students with feedback.

Although one teacher can help students develop how to engage in the practice and learn content by using the framework and instructional practices in her or his teaching, we see the potential of the framework in promoting student understanding across time.

### *Building the Use of the Practice Over Time*

Learning Scientists and science educators have proposed the use of a Learning Progression (LP) as a useful framework for helping students develop integrated understanding of a relatively small set of *big ideas* of science, including scientific practices (Duschl, Schweingruber, & Shouse, 2007; Wilson & Berenthal 2006, Smith, et al. 2006). Big ideas, synonymously used with core ideas, are defined as scientific ideas that are important for developing science literacy. They provide the learner with the ability to explain a broad range of phenomena within and between disciplines. Researchers see the value of learning progressions in building ideas over time because LPs can organize and align science content, instruction and assessment strategies to provide teachers with materials that can support students in building understanding of the big ideas over time. In this sense, learning progressions provide a potential path that can help student develop more sophisticated and useful ideas. As such, learning progressions (LP) are research-based descriptions of how students develop understanding of a big idea, moving from relatively novice to more expert understanding over a broad span of time (Duschl, Schweingruber, & Shouse, 2007; Smith et al., 2006). They show how learners can build and connect ideas to develop a more sophisticated understanding of an idea over time. Figure 2 shows a representation of learning progression. In this figure we match student development with performance on assessment tasks that can track ideas over time.

**Figure 2: Pictorial representation: A Generic Learning Progression**



Modified from Wilson (2005)

We present a hypothetical learning progression (Stevens, Delgado & Krajcik, accepted) for students developing understanding of constructing scientific explanations. A hypothetical learning progression is based on learning research and the structure of the idea, but has not been empirically tested (Shin, Stevens, Krajcik, accepted). A learning progression is necessarily considered hypothetically and must be revised iteratively based on the empirical research using promising instructional strategies to help students move from one level to the next. A LP that is tested iteratively and empirically under research conditions can then be considered a valid representation of developing understanding of a big idea.

## *A Hypothetical Learning Progression for Scientific Explanations*

Below we present a hypothetical learning progression of how students understanding of constructing scientific explanation might grow across grades 1 – 12. We show five variations of how students use of scientific explanations become more complex. Although we have based this progression on work we conducted in the field, research needs to be to evaluate the effectiveness of the progression to help support students to develop a richer understanding over time. Figure 3 provides an overview of the learning progression. We illustrate this hypothetical learning progression by providing possible students responses that increase in complexity over time. The student examples all focus on the general science topic of plant growth. Not only does the structure of the explanation become more complex across the five variations, but the science content also increases in complexity in a similar manner to the content standards for this topic in elementary, middle and high school.

Figure 3: Scientific Explanation Learning Progression (from McNeill & Krajcik, in preparation)

| **Level of Complexity** | **Framework Sequence** |
|---|---|
| Simple | Variation #1<br>1. Claim<br>2. Evidence |
| | Variation #2<br>1. Claim<br>2. Evidence<br>3. Reasoning |
| | Variation #3<br>1. Claim<br>2. Evidence<br>• Appropriate<br>• Sufficient<br>3. Reasoning |
| | Variation #4<br>1. Claim<br>2. Evidence<br>• Appropriate<br>• Sufficient<br>3. Reasoning<br>• Multiple components |
| Complex | Variation #5<br>1. Claim<br>2. Evidence<br>• Appropriate<br>• Sufficient<br>3. Reasoning<br>• Multiple components<br>4. Rebuttal |

### *Variation 1: Making a claim and providing simple evidence*

The first variation focuses on students simply providing a claim and supporting that claim with evidence. Students should be able to 1) Make a claim that includes a statement that answers the question, and 2) Provide evidence which is scientific data that supports the claim. This variation of the framework is particularly important for younger elementary students, such as Grades 1 and

2, who have little experience with engaging in this type of practice. An example of a scientific explanation for plant growth that just includes a claim and evidence is:

> The plant that received more light grew taller. (claim) The plant with 24 hours of light grew 20 cm. The plant with 12 hours of light only grew 8 cm. (evidence)

This example provides a simple claim, which is then supported with evidence.

***Variation 2: Adding Reasoning***

The next variation of the scientific explanation framework adds the reasoning component. In this variation students should be able to: 1) Make a claim that includes a statement that answers the question, 2) Give evidence which is scientific data that supports the claim, and 3) Provide reasoning that gives a justification for why the evidence supports the claim using scientific principles. This variation of the framework could be a potential entry place for older students such as upper elementary, middle or high school students. If students have had little experience supporting claims in science, starting with these three components can help support them in their thinking, talking and writing to appropriately justify the claims that they make. An plant growth example for this variation is:

> The plant that received more light grew taller. (claim) The plant with 24 hours of light grew 20 cm. The plant with 12 hours of light only grew 8 cm (evidence) Plants require light to grow and develop. This is why the plant that received 24 hours of light grew taller. (reasoning)

In this example, the claim and evidence are actually identical to Variation #1, but here students are also asked to articulate why the evidence supports the claim. The reasoning in this example is fairly simple, but it encourages students to begin thinking about why their data counts as evidence to support the claim and why they would not use different evidence or construct a different claim from this data.

***Variation 3: Using more complex data***

The third variation still contains the three components of claim, evidence and reasoning, but the complexity of the evidence increases. In this variation students should be able to: 1) Make a claim that includes a statement that answers the question, 2) Give evidence which is scientific data that supports the claim and that is both appropriate and sufficient in supporting the claim, and 3) Provide reasoning that gives a justification for why the evidence supports the claim using scientific principles. The focus in the previous two variations was just to include evidence. Here the evidence becomes more complex as students consider various characteristics of the evidence such as whether it is appropriate for the claim and whether or not they have sufficient evidence. The two characteristics are specifically targeted because students can struggle with differentiating between data that is and is not appropriate for evidence, such as using opinion instead of scientific data. Students can also focus on one piece of evidence instead of considering multiple pieces. The plant growth example increases in complexity:

> The plant that received more light grew more. (claim) On average for the six plants that received 24 hours of light, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants

> that received 12 hours of light, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Plants require light to grow and develop. This is why the plant that received 24 hours of light grew more (reasoning).

The scientific explanation example now includes multiple pieces of evidence; furthermore, the evidence includes both quantitative measurements and qualitative observations. Obviously, the data that the students either collected or were provided with would also have been more complicated and would have required greater analysis.

### *Variation 4: Providing complex reasoning*

The fourth variation also still contains the three main components of claim, evidence and reasoning, but now in addition to the evidence being more complex students are also required to include more complex reasoning. Students should be able to: 1) Make a claim that includes a statement that answers the question, 2) Give evidence which is scientific data that supports the claim and that is both appropriate and sufficient in supporting the claim, and 3)Provide reasoning that justifies why each piece of evidence supports the claim using scientific principle where each piece of evidence may have a different justification for why it supports the claim. The reasoning piece can become more complex in its use of scientific principles or it can become more complex in that different pieces of evidence require different reasoning to articulate how the evidence supports the claim. In the plant growth example, not only does the reasoning become more complicated but the claim that students are justifying has also become more complex:

> Plants need water, carbon dioxide and light to grow. (claim) On average for the six plants that received constant light, carbon dioxide and water, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants that received 12 hours of light, limited carbon dioxide and limited water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Photosynthesis is the process where green plants produce sugar from water, carbon dioxide and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide and light grew the most. (reasoning)

In the previous examples, the claim focused on how light effects plant growth. This example becomes more complex in that students are being asked what factors impact plant growth. This question requires a greater understanding of the science concepts related to plant growth and that water, carbon dioxide and light are necessary for photosynthesis to occur. Although we are just illustrating in these examples the product that the students would be producing, these variations would also require an increase in complexity in terms of the question being asked and the data that is being collected or provided to the students.

### *Variation 5: Adding rebuttals*

The final variation includes a specific focus on the rebuttal. In the rebuttal students articulate why another claim would not be more appropriate to answer a question or problem and provide counter evidence and/or reasoning to support that rationale. In this final variation, students should be able to: 1) Make a claim that includes a statement that answers the question, 2) Give evidence that is both appropriate and sufficient in supporting the claim, 3) Provide reasoning that justifies why each piece of evidence supports the claim using scientific principle where each piece of evidence may have a different justification for why it supports the claim, and 4) Include a rebuttal describes alternative explanations and provides counter evidence and reasoning for why the alternative is not appropriate. The only difference in this example for plant growth is the last section of the explanation focused on the rebuttal:

> Plants need water, carbon dioxide and light to grow. (claim) On average for the six plants that received constant light, carbon dioxide and water, they grew 20 cm, had six yellow flowers, had fifteen leaves and they were all vibrant green. On average for the six plants that received 12 hours of light, limited carbon dioxide and limited water, they grew 8 cm, had two yellow flowers, and had four leaves. Also, two of the plants had zero flowers. These plants were still vibrant green, but they were smaller with fewer flowers and leaves. (evidence) Photosynthesis is the process where green plants produce sugar from water, carbon dioxide and light energy. Producing sugar is essential for plant growth and development. That is why the plants that received a constant source of water, carbon dioxide and light grew the most. (reasoning) Our experimental design just limited the amount of air the plants received not specifically the amount of carbon dioxide. So you could argue that plants need water, air and light. But we know that the process of photosynthesis requires carbon dioxide and not another gas (like oxygen), which is why we concluded specifically that the carbon dioxide was required for growth. If we could limit just the carbon dioxide in our design, we would have better evidence for this claim (rebuttal).

This example does not require a more complex learning task in terms of the question or the data set. Rather the complexity increases because of the expectation of the teacher that his or her students should be including a rebuttal in their response. Consequently, we can also imagine situations in which students provide a rebuttal even though their evidence and/or reasoning is less complex resembling more closely variation 2 or 3 plus the rebuttal. This suggests that the inclusion of the rebuttal may make more sense earlier in the learning progression. The rebuttal could also include multiple variations from simple to more complex suggesting a separate learning progression for this component.

## *A Curriculum Example of Building Ideas Across Time*

The Investigating and Questioning our World through Science and Technology (IQWST) curriculum, has used these instructional strategies to support students across the middle grade years in developing a robust and flexible expertise in constructing evidence-based scientific explanations. IQWST is a three year curriculum for 6th, 7th and 8th grades with each year consisting of four units one for each of the different science domains: biology, chemistry, earth science and physics. One major goal of the IQWST curriculum is to help students develop increasing expertise with constructing, defending and evaluating evidence-based scientific explanations, over the three years of middle school. Experts in learning (learning scientists and cognitive psychologists) recognize that for students to develop sophisticated understanding of a complex science idea, ideas need to be developed over time and they must be built from understandings of other related concepts and principles (Wilson & Berenthal, 2006; Bransford, & Donovan, 2005). As such, we have designed three years of coherent curriculum materials in which we have carefully sequenced students' understanding of both core ideas of science and of various scientific practices (Krajcik, McNeill & Resier, 2008, Shwartz, Weizman, Fortus, Krajcik, & Reiser, accepted). Each year in the IQWST curriculum we focus on helping students develop deeper, more flexible and more useful understandings of constructing explanations.

We introduce the ideas of scientific explanations and the framework of claim, evidence, and reasoning in the 6th grade biology unit and then throughout the year we focus on helping students develop what is meant by evidence. The understanding students develop is then extended in the 7th grade building further student understanding of evidence and by focusing on reasoning and how the use of scientific ideas is critical in the reasoning process. In the eighth grade, we further develop students understanding of scientific explanation continuing to go deeper in the practice by adding aspects of ruling out alternative explanations through the use of rebuttals. By the end of 8th grade, students will have a rich understanding and a variety of experiences in constructing scientific explanations.

### ***Student Learning for Scientific Explanation***

During the IQWST 7th chemistry unit, "*How can I make new stuff from old stuff?*" or *Stuff*, we explored student learning of scientific explanations. The *Stuff* unit is a 2 month unit that focuses on three main scientific concepts: 1) substances & properties, 2) chemical reactions, and 3) conservation of mass. During the unit, students begin by exploring two unknown to determine whether or not they are the same substances. After using a variety of properties such as density, melting point, and solubility to determine that the two unknowns (fat and soap) are different substances, students then explore chemical reactions. Students conduct a number of investigations where they combine different substances and determine whether or not a chemical reaction has occurred. Finally, they explore whether or not mass stays the same during chemical reactions as well as other processes such as phase changes and mixtures. In the context of these different investigations, students frequently analyze their data and write scientific explanations. Students have up to thirteen opportunities to write scientific explanations depending on the teachers use of the curriculum.

During the 2004-2005 school year, we investigated how students' scientific explanations changed over the course of the school year when they were provided with both teacher instructional support and curricular scaffolds (McNeill, 2006; McNeill & Krajcik, in press). We worked with six teachers and their 568 seventh grade students. We collected pre and posttests from the students as well as student writing samples from three different lessons during the curriculum: 1) Lesson 6 focused on substances and properties, 2) Lesson 8 focused on chemical reactions and 3) Lesson 13 focused on conservation of mass.

### *Pre to Posttest*

We first examined student learning from the pretest to the posttest. 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. Of these students, 56% of the students were female and 44% of the students were male. 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 1.

**Table 1: 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*.

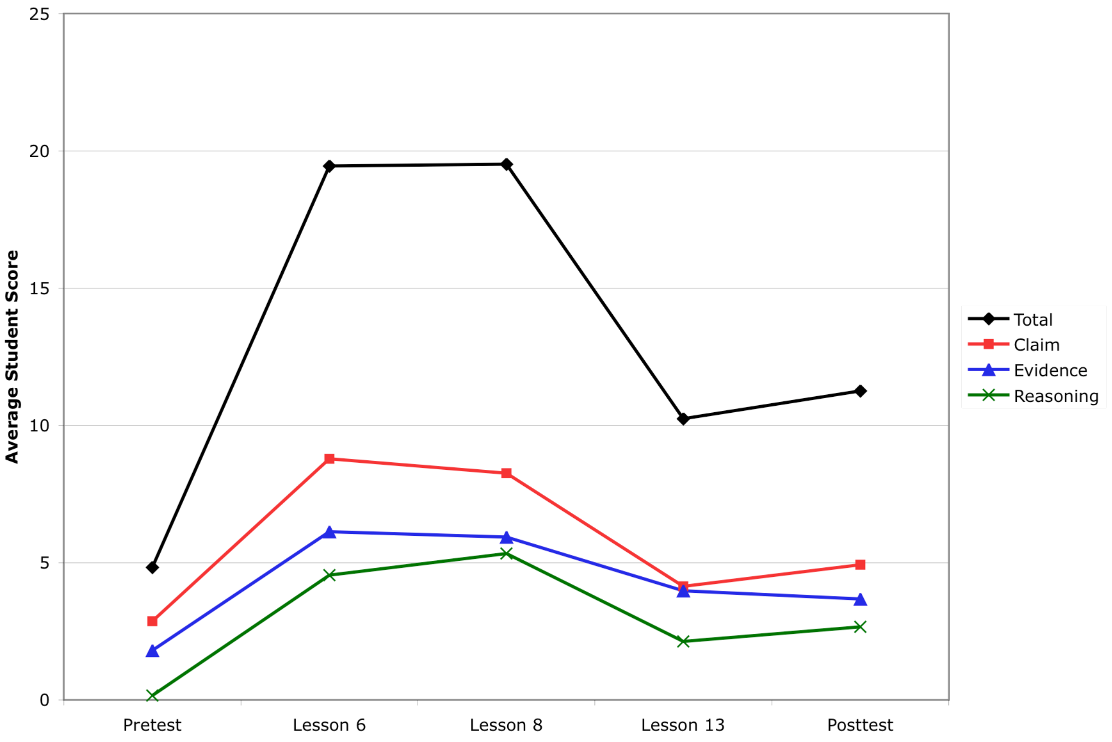
*** $p < .001$

Across all teachers, students achieved 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 lower than the claim and evidence average. Similar to our previous work (McNeill & Krajcik, in press; McNeill et al., 2006), the claim appears to be the easiest component for students. Overall, the learning gains are significant yet there also appears to be room for improvement.

### *Across Time*

Next, we were interested in examining student learning across time. We received completed student investigation books with scientific explanations from 227 students of the 328 students included in the rest of the analysis. Figure 4 displays the students' average score on the pretest, Lesson 6, Lesson 8, Lesson 13, and the posttest to provide a visual representation of the changes over time[1]. Since all the students did not complete all three scientific explanations in their student books, the average at each time point is only for those students who wrote the corresponding scientific explanation.

Figure 4: Students' Scientific Explanation Scores Across Time



For students' complete scientific explanation score, there is a large jump from the pretest to Lesson 6 and Lesson 8, while students' scientific explanations are much lower during Lesson 13, which focused on conservation of mass. During these three lessons, students' written scientific explanations do not represent each student's individual and independent ability to write a scientific explanation. Rather, they represent a student's ability to write a scientific explanation when they are provided with a variety of supports such as the curricular supports, teacher instructional practices and their peers. This differs from the pre and posttest when students write scientific explanations independently. This may be one reason why there is such a large jump from the pretest to Lesson 6. Students receive help in terms of what they should include in their explanation.

The decrease in students' scientific explanations in Lesson 13 could have been caused by a variety of different factors including the fading of curricular support, the difficulty of the content

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[1] All scientific explanations were scored using specific rubrics adapted from the same base rubric with a maximum score of 3.0 for claim, evidence and reasoning. On the pre and posttest measures, students wrote three scientific explanations so the highest possible score was 9.0. Since the majority of the analysis in the results section focuses on the test score, we decided to weight the artifacts for the highest possible score of 9.0. On the base rubric, a score of 9 corresponds to a level 3, a score of 6 corresponds to a level 2, and a score of 3 corresponds to a level 1.

or decreased teacher support. The results of a previous study that we conducted suggest that the decrease in student scores was not caused solely by the fading curricular support. In previous work (McNeill et al., 2006), we tested the effect of fading written curricular support compared to continuous written curricular support where the support remained constant throughout the *Stuff* unit. We observed a similar pattern in students' written scientific explanations in this previous study in which students' scores increased greatly in the focal lesson, which is equivalent to Lesson 6 here, and then decreased in later explanations where the content of the explanations focused on conservation of mass.

There is evidence from students' posttests that supports the idea that the conservation of mass content was particularly hard for students. We examined students' posttest multiple-choice test scores comparing the equally weighted conservation of mass items ($M$ =2.88, $SE$ = 0.11) with the substance and property items ($M$ = 3.94, $SE$ = 0.09) and the chemical reaction items ($M$ = 3.57, $SE$ = 0.09)[2]. We conducted paired t-tests and found that students scored significantly lower on the conservation of mass multiple-choice items compared to both the substance and property items, $t$ (327) = 10.96, $p < .001$, and the chemical reaction items, $t$ (327) = 7.54, $p < .001$. In terms of writing scientific explanations on the posttest, again the conservation of mass explanation ($M$ =2.66, $SE$ = 0.13) was more difficult for students than the equally weighted substance and property explanation ($M$ =3.10, $SE$ = 0.18) or the chemical reaction explanation ($M$ =3.82, $SE$ = 0.15)[3]. Again, we conducted paired t-tests and found that students scored significantly lower on their conservation of mass scientific explanations compared to both their the substance and property explanations, $t$ (327) = 2.91, $p < .01$, and their chemical reaction explanations, $t$ (327) = 8.17, $p < .001$. This provides additional evidence that the conservation of mass content was more difficult for students.

Finally, in terms of teacher support, another possibility for why this decrease in students' explanation scores occurred is that the teachers may have provided students with less support during Lesson 13 in writing their scientific explanations.

## *Concluding Comments*

Scientific explanation/argumentation is a key learning goal for k-12 students and stressed in reform documents (Duschl et al., 2007) and the national science education standards (AAAS, 1993; NRC, 2000). This essential scientific practice provides opportunities for students to use evidence and reasoning to make sense of how or why a phenomenon occurred. Yet the research shows that not only do students have difficulty supporting their claims with appropriate evidence and reasoning (Bell & Linn, 2000; Jiménez-Aleixandre,et al., 2000; Sadler, 2004; Sandoval & Millwood, 2005), they are seldom given opportunities to engage in the practice. Our previous research work, shows that the framework (claim, evidence, reasoning and rebuttal) can break down this complex task so that students can take part in this important scientific practice and show learning gains. We also presented different variations of the framework that can be introduced to students over time as their abilities increase. Although we do not as yet have data to support this progression, we do have empirical support that shows that students who use the

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[2] For all three content areas, We weighted the multiple-choice scores to have the same maximum score of 6.0

[3] The highest possible overall score for a scientific explanation was 9.0.

framework improve in constructing scientific explanation across an 8 – 10 week unit. As such work adds to the growing body of literature on learning progressions that describes how students understanding develops over time (Duschl, R. A., Schweingrube & Shouse, 2007; Wilson, & Berenthal, 2006; Stevens, Delgado & Krajcik, accepted). Our work also shows that reasoning component is the most difficult component for students to learn. However, if focused on over a school year and across school years, students will have a greater opportunity to develop the reasoning component; however, we do recognize that the reasoning component is tied to understanding specific content.

Other curriculum like IQWST need to be built to support students not only in the practice of constructing explanations but in other key practices such as asking questions and modeling (Schwartz, Resier, Davis, et al., accepted). However, students at any grade level will only learn various practices if teachers also provide additional supports such as modeling and giving feedback. The next stage of our research will need to investigate the hypothetical learning progression we provide to evaluate the effectiveness of this progression in supporting students over time (Stevens, Delgado & Krajcik, accepted; Shin, Stevens, Krajcik, accepted).

Although the framework presents a simple model of supporting learners in the process of constructing scientific explanations, our research work and our interactions with teacher indicate that it accessible to both teachers and learners in elementary, middle and high school that allows them to engage in the construction of evidence-based scientific explanations. If the NARST research community hopes to make an impact on teaching practice, we need to work closely with teachers to develop frameworks like CER that is accessible to practicing teachers and their students for other scientific practices.

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