ASSESSING MIDDLE SCHOOL STUDENTS’ CONTENT KNOWLEDGE AND SCIENTIFIC
REASONING THROUGH WRITTEN EXPLANATIONS

Joseph S. Krajcik and Katherine L. McNeill
University of Michigan

Modified from McNeill, K. L. & Krajcik, J. (2011). Supporting grade 5-8 students in
constructing explanations in science: The claim, evidence and reasoning framework for talk

contact info:
Center for Highly Interactive Classrooms, Curricula & Computing in Education
610 E. University Ave., Ann Arbor, MI, 48109-1259
734-647-4226
krajcik@umich.edu

Workshop presented at the University of Maine, "No Question Left Behind: Bringing Guided
Inquiry Curriculum Materials into the Classroom” June 23rd & 24th, 2011.

This research was conducted as part of the Investigating and Questioning our World through Science and
Technology (IQWST) project, supported in part by the National Science Foundation grants ESI 0101780.
Any opinions expressed in this work are those of the authors and do not necessarily represent either those
of the funding agency or the University of Michigan.
**NATIONAL MIDDLE SCHOOL SCIENCE STANDARDS RELATED TO SCIENTIFIC EXPLANATION**

The standards below come from *Benchmarks for Science Literacy* by the American Association for the Advancement of Science (AAAS, 1993).

Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence. (AAAS, 1B: 1, 6-8)

Know that often different explanations can be given for the same evidence, and it is not always possible to tell which one is correct. (AAAS, 12A: 3, 6-8)

Notice and criticize the reasoning in arguments in which (1) fact and opinion are intermingled or the conclusions do not follow logically from the evidence given, (2) an analogy is not apt, (3) no mention is made of whether the control groups are very much like the experimental group, or (4) all members of a group (such as teenagers or chemists) are implied to have nearly identical characteristics that differ from those of other groups. (AAAS, 12E: 5, 6-8)

The standards below come from *National Science Education Standards* by the National Research Council (NRC, 1996).

Develop...explanations... using evidence. (NRC, 1996, A: 1/4, 5-8)

Think critically and logically to make the relationships between evidence and explanation. (NRC, 1996, A: 1/5, 5-8)

Recognize and analyze alternative explanations and predictions. (NRC, 1996, A: 1/6, 5-8)

Communicate scientific procedures and explanations. (NRC, 1996, A: 1/7, 5-8)

Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances. (NRC, A2/5:5-8)

Science advances through legitimate skepticism. Asking questions and querying other scientists’ explanations is part of scientific inquiry. Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identify faulty reasoning pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations. (NRC, A2/6:5-8)

“Essential features of classroom inquiry” as described by the National Research Council (2000).

Learners are engaged in scientifically oriented questions.

Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.

Learners formulate explanations from evidence to address scientifically oriented questions.

Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.

Learners communicate and justify their proposed explanations.
# Essential Features of Classroom Inquiry and Their Variations

<table>
<thead>
<tr>
<th>Essential Feature</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner engages in scientifically oriented questions</td>
<td>Learner poses a question</td>
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<tr>
<td></td>
<td>Learner selects among questions, poses new questions</td>
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<tr>
<td></td>
<td>Learner sharpens or clarifies question provided by teacher, materials, or other sources</td>
</tr>
<tr>
<td></td>
<td>Learner engages in question provided by teacher, materials, or other sources</td>
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<tr>
<td>Learner gives priority to evidence in responding to questions</td>
<td>Learner determines what constitutes evidence and collects it.</td>
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<tr>
<td></td>
<td>Learner directed to collect certain data</td>
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<td></td>
<td>Learner given data and asked to analyze</td>
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<tr>
<td></td>
<td>Learner given data and told how to analyze</td>
</tr>
<tr>
<td>Learner formulates explanation from evidence</td>
<td>Learner formulates explanation after summarizing evidence</td>
</tr>
<tr>
<td></td>
<td>Learner guided in process of formulating explanation from evidence</td>
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<tr>
<td></td>
<td>Learner given possible ways to use evidence to formulate explanation</td>
</tr>
<tr>
<td></td>
<td>Learner provided with evidence</td>
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<tr>
<td>Learner connects explanations to scientific knowledge</td>
<td>Learner independently examines other resources and forms the links to explanations</td>
</tr>
<tr>
<td></td>
<td>Learner directed toward areas and sources of scientific knowledge</td>
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<tr>
<td></td>
<td>Learner given possible connections</td>
</tr>
<tr>
<td>Learner Communicates and justifies explanations</td>
<td>Learner forms reasonable and logical arguments to communicate explanation</td>
</tr>
<tr>
<td></td>
<td>Learner coached in development of communications</td>
</tr>
<tr>
<td></td>
<td>Learner provided broad guidelines to sharpen communications</td>
</tr>
<tr>
<td></td>
<td>Learner given steps and procedures for communications</td>
</tr>
</tbody>
</table>

More------------------------Amount of Learner Self Direction---------------------------Less
Less------------------------Amount of Direction from Teacher or Material---------------------------More

Adapted from *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (p. 29, NRC, 2000)
INSTRUCTIONAL MODEL FOR SCIENTIFIC EXPLANATION

WHY SCIENTIFIC EXPLANATIONS?
Science education reform efforts call for students to develop scientific processes and skills through inquiry (American Association for the Advancement of Science, 1993; National Research Council, 1996). One prominent inquiry practice in both the standards documents and research literature is the construction, analysis, and communication of scientific explanations. We believe that explanation construction should be an important part of science class for multiple reasons. First, research into scientists’ practices portrays a picture where scientists construct arguments or explanations including weighing evidence, interpreting text, and evaluating claims (Driver, Newton & Osborne, 2000). Second, previous research in science education has found that having students engage in explanation may change or refine their image of science as well as enhances their understanding of the nature of science (Bell & Linn, 2000). Third, constructing explanations can enhance student understanding of the science content (Driver, Newton & Osborne, 2000). Finally, assessing students’ scientific explanations can help make their thinking visible both in terms of their understanding of the science content and their scientific reasoning (McNeill & Krajcik, in press).

WHAT IS A SCIENTIFIC EXPLANATION?
A scientific explanation is a written or oral response to a question that requires students to analyze data and interpret that data with regard to scientific knowledge. Our explanation framework includes three components: claim, evidence, and reasoning. While we break down explanations into these three components for students, our ultimate goal is to help students to create a cohesive explanation in which all three components are linked together. Yet we have found that first breaking explanations down into the three components can ultimately help students create cohesive explanations. In the following section, we describe the three components of a scientific explanation.

Claim
The claim is a testable statement or conclusion that answers the original question. The claim is the simplest part of an explanation and often the part students find the easiest to include as well as to identify when they are critiquing other peoples’ explanations. One of the purposes in focusing on scientific explanations is to help students include more than a claim in their writing.

Evidence
The evidence is scientific data that supports the student’s claim. This data can come from an investigation that students complete or from another source, such as observations, reading material, archived data, or other sources of information.

The data needs to be both appropriate and sufficient to support the claim. When introducing evidence to middle school students, we suggest discussing appropriate data in terms of whether the data supports the claim. A good explanation only uses data that supports the claim in answer to the original question. Students should also consider whether or not they have sufficient data. When introducing this concept to middle school students, we suggest discussing sufficient data in terms of whether they have enough data.
When students are selecting their data to use as evidence, they should consider both whether it is appropriate to support their claim and whether they have enough data to support their claim. We have found that this can be difficult for students. While they realize that they should include data as evidence, they are not necessarily sure which data to use or how much data to use.

**Reasoning**

Reasoning is a justification that shows why the data counts as evidence to support the claim and includes appropriate scientific principles. The reasoning ties in the scientific background knowledge or scientific theory that justifies making the claim and choosing the appropriate evidence.

We have found that students have a difficult time including the entire reasoning component. Often students simply make a general link between the claim and evidence. You want to help students learn to include the scientific background knowledge that allowed them to make that connection between claim and evidence.

**How To Support Students’ Construction of Scientific Explanations**

Many middle school children will find constructing scientific explanations difficult. It is not an inquiry practice that they can learn quickly. Students need support in terms of when, how, and why to use the claim, evidence, and reasoning framework. We suggest using a number of techniques to help students with this complex practice.

1. **Make the framework explicit.** You want to help students understand the three components of explanations. They should understand what these three components are as well as the definitions of claim, evidence and reasoning.

2. **Discuss the rationale behind explanation.** Students need to understand not only what an explanation is, but also why people construct an explanation. Understanding the logic behind scientific explanation can help students when they are engaging in this practice. For example, you may want to talk to students about how just providing a claim is not very convincing or persuasive. Providing evidence and reasoning creates a stronger case for why a claim is correct.

3. **Model the construction of explanations.** After introducing explanations, you want to model how to construct explanations through your own talking and writing. When it is appropriate, provide students with examples of explanations. Furthermore, identify for students where the claim, evidence, and reasoning were in your own example.

4. **Discuss similarities and differences with everyday explanations.** Just like in science, in everyday life people try to convince each other of claims. You may want to provide students with an everyday example, like discussing the best musician or athlete, and discuss how the claim, evidence and reasoning framework can be used. Although scientific explanations can be very similar to everyday explanations, they can also be quite different. When people use the word “explain” in everyday talk, they are often not asking for someone to provide evidence and reasoning for a claim. For example, someone might ask you: Can you explain to me where the grocery store is? In this case, the meaning of explain corresponds more closely with describe than to the scientific explanation framework. Students can develop a more complete understanding of
scientific explanation if they understand how it is similar and different from everyday explanations.

5. **Provide multiple opportunities to construct explanations.** Provide numerous opportunities for students to construct explanation through various investigations. These explanations promote student learning and make great formative/embedded feedback. During class discussions, if a student makes a claim ask them to provide an explanation for that claim. Encourage students to provide evidence and reasoning to support their claims.

6. **Have students critique explanations.** When students write explanations in class, you may want to have them trade their explanations with a neighbor and critique each other’s explanations. Focus students’ attention on discussing both the strengths and weaknesses of their partners’ explanations and offering concrete suggestions for improvement. You may want to show students an overhead of a generic student’s response and as a class critique the explanation. Or you may want to provide students with an example of a scientific explanation from a newspaper, magazine or website. Then you could have students critique the explanation in terms of the claim, evidence, and reasoning.

7. **Provide students with feedback.** When students construct explanations, provide explicit and thorough feedback. You should comment on their explanation as a whole as well as the quality of the individual components. You may want to coach them on how to improve their explanations by asking them leading questions or providing them with examples. For example, you may want to ask students what the reasoning was in their explanation and how they might improve their reasoning. Explicit and thorough feedback that provides suggestions for improvement promotes student understanding.

While supporting students’ construction of scientific explanations can be a time-consuming process, there are numerous benefits. Helping students understand and be able to construct explanations can result in a greater understanding of science content and science as an inquiry process.
### BASE EXPLANATION RUBRIC

<table>
<thead>
<tr>
<th>Component</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
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<tbody>
<tr>
<td><strong>Claim</strong> – A conclusion that answers the original question.</td>
<td>Does not make a claim, or makes an inaccurate claim.</td>
<td>Makes an accurate but incomplete claim.</td>
<td>Makes an accurate and complete claim.</td>
</tr>
<tr>
<td><strong>Evidence</strong> – Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.</td>
<td>Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).</td>
<td>Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.</td>
<td>Provides appropriate and sufficient evidence to support claim.</td>
</tr>
<tr>
<td><strong>Reasoning</strong> – A justification that links the claim and evidence. It shows why the data counts as evidence by using appropriate and sufficient scientific principles.</td>
<td>Does not provide reasoning, or only provides reasoning that does not link evidence to claim.</td>
<td>Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.</td>
<td>Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.</td>
</tr>
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</table>

The base explanation rubric is a general rubric for scoring scientific explanations across different content and learning tasks (McNeill, Lizzotte, Krajcik & Marx, 2006). It includes the three components of a scientific explanation and offers guidance to think about different levels of student achievement for each of those components. The base rubric needs to be adapted to create a specific rubric for a particular task (see next page). The specific rubric combines both the general structure of a scientific explanation with the appropriate science content for the particular task.
### SCIENTIFIC EXPLANATION: SUBSTANCE AND PROPERTIES

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<td>Makes an accurate but incomplete claim.</td>
<td>Makes an accurate and complete claim.</td>
</tr>
<tr>
<td></td>
<td>States none of the liquids are the same or specifies the wrong solids.</td>
<td>Vague statement, like “some of the liquids are the same.”</td>
<td>Explicitly states “Liquids 1 and 4 are the same substance.”</td>
</tr>
<tr>
<td><strong>Evidence</strong> – Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.</td>
<td>Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).</td>
<td>Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.</td>
<td>Provides appropriate and sufficient evidence to support claim.</td>
</tr>
<tr>
<td></td>
<td>Provides inappropriate data, like “the mass is the same” or provides vague evidence, like “the data table is my evidence.”</td>
<td>Provides 1 or 2 of the following pieces of evidence: density, melting point, and color of liquids 1 and 4 are the same. May also include inappropriate evidence, like mass.</td>
<td>Provides all 3 of the following pieces of evidence: density, melting point, and color of liquids 1 and 4 are the same.</td>
</tr>
<tr>
<td><strong>Reasoning</strong> – A justification that links the claim and evidence. It shows why the data counts as evidence by using appropriate and sufficient scientific principles.</td>
<td>Does not provide reasoning, or only provides reasoning that does not link evidence to claim.</td>
<td>Repeats evidence and links it to the claim. May include some scientific principles, but not sufficient.</td>
<td>Provides accurate and complete reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.</td>
</tr>
<tr>
<td></td>
<td>Provides an inappropriate reasoning statement like “they are like the fat and soap we used in class” or does not provide any reasoning.</td>
<td>Repeats the density, melting point, and color are the same and states that this shows they are the same substance. Or provides an incomplete generalization about properties, like “mass is not a property so it does not count.”</td>
<td>Includes a complete generalization that density, melting point, and color are all properties. Same substances have the same properties. Since liquids 1 and 4 have the same properties, they are the same substance.</td>
</tr>
</tbody>
</table>
CREATING EXPLANATION ASSESSMENT TASKS

In order to create assessment tasks that measure students’ ability to write scientific explanations, we use a number of steps. These steps help ensure that the task is appropriate for having students construct an explanation in terms of combining both their understanding of the content and scientific explanation. The steps also help align the task with the desired national science content standards and make certain that the task actually measuring the desired content.

1. **Select and unpack the content idea.** There are often far more ideas in one content standard than you might initially think. It is important to closely examine and unpack the content standards to determine the science ideas that you are trying to help students learn as well as assess (McNeill & Krajcik, in press). When interpreting standards it can be helpful to: 1. Decompose the standard into related concepts 2. Clarify the different concepts. 3. Consider what other concepts are needed and 4. Make links if needed to other standards. Furthermore, it is important to consider what prior knowledge students will need to understand this concept as well as what non-normative ideas or misconceptions they may have about the content. You may decide to include some of the non-normative ideas in your design of the assessment item.

2. **Unpack the scientific inquiry practice.** It is important to consider what you are looking for in terms of the scientific inquiry practice (e.g. design, analyze, explanation). We unpacked explanation into three components: claim, evidence and reasoning. This unpacking corresponds to the base rubric and clearly articulates what you are looking for in terms of the assessment task. If you create an assessment item for a different scientific inquiry practice (e.g. design of investigation), you would need to unpack the practice and create a corresponding base rubric.

3. **Create learning performance.** The scientific explanation assessment task measures both students understanding of the science content and the scientific inquiry practice. In order to help us think about what it means to combine the content and inquiry practice, we first create learning performances. Learning performances specify what we what students to be able to do with the content knowledge. You can think of a learning performance as a cross between the content standard and an inquiry practice. The learning performance clarifies how the content knowledge is used in reasoning about a scientific phenomenon.

4. **Write the assessment task.** Next we create an assessment item that would result in students applying both their content and explanation understandings to create the desired product. We do this by aligning the assessment task to the learning performance that we previously create. We also create a specific rubric for that particular assessment task by determining what would count as appropriate and sufficient claim, evidence, and reasoning. The specific rubric differs from the basic rubric in that it is specific to a task and shows clearly what content knowledge and evidence the students should apply.

5. **Review assessment item.** After creating the assessment task, use three questions adapted from the Project 2061’s assessment framework (DeBoer, 2005) to review our item: 1. Is the knowledge needed to correctly respond to the task? 2. Is the knowledge enough by itself to correctly respond to the task or is additional knowledge needed? 3. Is the assessment task and context likely to be comprehensible to students?
Creating appropriate assessment tasks and the corresponding specific rubrics is a difficult task. Yet once you have developed the tasks and rubrics, they can help you better assess students’ understanding of the science content as well as students’ reasoning behind their understanding of phenomena.

REFERENCES
Examine the following data table:

<table>
<thead>
<tr>
<th></th>
<th>Density</th>
<th>Color</th>
<th>Mass</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid 1</td>
<td>0.93 g/cm³</td>
<td>no color</td>
<td>38 g</td>
<td>-98 °C</td>
</tr>
<tr>
<td>Liquid 2</td>
<td>0.79 g/cm³</td>
<td>no color</td>
<td>38 g</td>
<td>26 °C</td>
</tr>
<tr>
<td>Liquid 3</td>
<td>13.6 g/cm³</td>
<td>silver</td>
<td>21 g</td>
<td>-39 °C</td>
</tr>
<tr>
<td>Liquid 4</td>
<td>0.93 g/cm³</td>
<td>no color</td>
<td>16 g</td>
<td>-98 °C</td>
</tr>
</tbody>
</table>

Write a scientific explanation that states whether any of the liquids are the same substance.

**Scientific Explanation 1**

Write a scientific explanation that states whether any of the liquids are the same substance. Liquid 1 and 4 are the same substance. They both have a density of 0.93 g/cm³, have no color, and start to melt at -98 °C. For substances to be the same, they must have the same properties. Since liquids 1 and 4 have the same properties, they are the same substance. The other 2 liquids are different substances because they have different properties.
Scientific Explanation 2

Write a scientific explanation that states whether any of the liquids are the same substance.

I believe that liquid 1 and liquid 4 are the same substance. Their densities and melting point are the same. The mass is different, but that only means that the portion or part is smaller than the other. Like butter, the mass does not have to be the same but the melting point and density are the same. Therefore, I believe that liquid 1 and 4 are the same substance.

Scientific Explanation 3

Write a scientific explanation that states whether any of the liquids are the same substance.

Two of these substances are the same because liquid 1 and liquid 4 have the same density and melting point. But not the mass, but their could be more water in liquid 1 than liquid 4 or a larger container.
Scientific Explanation 4

Write a **scientific explanation** that states whether any of the liquids are the same substance.

Liquids 1 and 4 are the same substance. A substance is something that is made of the same atoms and molecules throughout. Mass is not a property because the mass can change. Liquids 1 and 4 have the same properties. So they are the same substance. Therefore, Liquids 1 and 4 are the same because their properties are the same.

Scientific explanation 5

Write a **scientific explanation** that states whether any of the liquids are the same substance.

None of the liquids are the same. Some of the data is similar but the main properties that help determine if they are the same don’t match. The melting points are all different. Liquid #1 and #4 seem similar but have different mass measurements.