# Characterizing the Quality of Second-Graders' Observations and Explanations to Inform the Design of Educative Curriculum Materials

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**Abstract:** Recording observations and constructing evidence-based explanations are key aspects of inquiry-oriented science teaching and are essential to learning authentic science. However, little is known about the kinds of observations and explanations early elementary school students can make and the ways educative curriculum materials can support students' and teachers' learning about these inquiry practices. In this study, we describe the quality of second graders' drawings and descriptions of their observations and the explanations they construct from their observations during an inquiry-based unit. Our results show that despite some success in making drawings, descriptions, and explanations, children still face many difficulties when engaged in these inquiry tasks. These findings suggest specific areas in which scaffolding for students may be warranted. The findings also point to areas where it may be important to provide additional guidance for teachers. We make recommendations for these student and teacher supports.

## Theoretical Framework

Reforms in science education emphasize inquiry-based instruction as essential for student learning (AAAS, 1993; NRC, 2000). Scientific inquiry entails engaging students in asking questions, implementing experiments to answer those questions, constructing explanations to describe data, and sharing findings with others (Krajcik, Blumenfeld, Marx, & Soloway, 2000). Two inquiry practices of particular interest in this study are the recording of observations and the construction of evidence-based explanations. Recording observations is an essential part of data collection because it involves describing and categorizing objects, organisms, and/or experiences in the natural world (NRC, 2000). By making careful observations, students can use these data as evidence to build scientific explanations. Developing evidence-based explanations entails using data as evidence to support a claim and using reasoning to show how evidence is related to that claim (Toulmin, 1958).

Engaging students in these two inquiry practices is important because recording observations of natural phenomena and using those observations to build explanations are fundamental to the work of practicing scientists (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Constructing explanations from observations of their everyday world also enables students to develop a rich conceptual understanding of knowledge (Bell, 2004; Driver, Newton, & Osborne, 2000). Students also gain greater insight into its epistemology (Sandoval, 2003), its methods of science investigation, and its nature as a social practice (Kuhn, 1993). For these reasons, students should be engaged in these inquiry practices when learning science.

However, forming evidence-based explanations is no easy task. Middle and high school students often fail to use data as evidence and instead use personal experiences or second-hand sources as evidence in their explanations (Driver et al., 2000; Kuhn, 1993) Students also struggle to differentiate between claims and evidence (Bell, 2004). Despite these difficulties, limited research findings have indicated that even children in the earliest grade levels can distinguish between inference and observation and draw conclusions from data when provided with support (Herrenkohl & Guerra, 1998; Lehrer & Schauble, 1998; Metz, 2000). In these ways, young students can engage in these inquiry practices.

Reform documents state that early elementary school students should make careful observations of their everyday world, decide what constitutes as evidence, and generate explanations by using their data to explain *how* they know something (AAAS, 1993; NRC, 1996). However, despite these guidelines and research findings, little is still known about how students in the earliest grades engage in these inquiry tasks and about the specific struggles they face. Therefore, little is known about how best to support students in engaging in these practices. In this study, we asked the question, *What is the quality of second grade students' drawings, descriptions, and explanations during an inquiry-based unit?* Gaining a better understanding of how young children make observations and develop scientific explanations can provide insight into the kinds of scaffolding that can be designed for educative curriculum materials to support both student and teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005). By developing and refining scaffolding for students and teachers, we may improve the quality of science education at the elementary level by providing opportunities for children to develop their inquiry skills at a young age and by helping teachers support their students as they engage in the inquiry process.

## Methods and Data Sources

This study was conducted in a classroom with 30 second-grade students as they worked on an inquiry-based plants unit. This 6-week unit was provided within the CASES website, an online learning environment for teachers (http://cases.soe.umich.edu; see Davis, Smithey, & Petish, 2004). This unit included five lessons that engaged students in making careful observations and using their observations as evidence to form explanations. These curriculum materials were intended to promote both student and teacher learning. With regards to supports for students, worksheets were designed with specific explanation prompts (Herrenkohl & Guerra, 1998; Sandoval, 2003). Such prompts included *specific* questions and sentence starters, such as, "Explanation: During your seed activities, what did you do or see that makes you think that your seed can move this way? I think my seed can move this way because…" In helping students record their observations, *general* supports for drawings and descriptions were included in the worksheets, such as, "Observation: Here is a picture of my seed," and, "Observation: Write and draw what your plant looks like." However, no *specific* supports were provided for recording observations because little is know about the kinds of supports students need for this particular inquiry task.

This small-scale study was part of a larger investigation that observed a beginning elementary teacher's practice with regard to explanation construction, but to inform that study of the teacher's practice, we were also interested in examining students' learning with regard to recording observations and constructing explanations. Field notes from classroom observations, lesson worksheets, and unit tests were collected. Students completed drawings in the lesson worksheets only, but they completed written descriptions and explanations in both the lesson worksheets and unit tests. In analyzing students' descriptions and explanations, we decided to combine the data from the student worksheets and unit tests for several reasons. The data were combined because the questions in the lesson worksheets were similar to the unit test and there were too few student descriptions and explanations to analyze if the data were kept separate. We were also not interested in looking at change over time but were interested primarily in describing the quality of descriptions and explanations students gave. Additionally, there was little difference in student performance on these inquiry tasks between the lesson worksheets and unit tests. We used descriptive statistics to describe the quality of students' drawings, descriptions, and explanations and complemented the data with examples from students' work.

Eleven *drawings* from each student were coded for analysis. These drawings were taken from all five lessons. Drawings included pictures of fruits, seeds, and plants. Pictures were excluded from analysis if restrictions on time prevented students from finishing their drawings. Codes to judge the quality of students' pictures included (1) accurate shape, (2) accurate size, (3) use of detail (accurate quantity and quality of distinct parts), and (4) use of color. Because of the lack of research on young children's observational drawings, this coding scheme emerged out of students' work. Children's drawings were also assigned an overall score, receiving a point for each code satisfied.

Four *descriptions* were analyzed for each student, two from lessons and two from the unit test. Descriptions included statements detailing the features of seeds, leaves, and plants. The quality of students' descriptions was judged based on sufficiency and appropriateness. (See Table 1.) Codes for *sufficiency* pertained to the number of details in a description. Codes for *appropriateness* described descriptions as using only appropriate details, only inappropriate details, or both. Details were deemed appropriate if they were (1) accurate, (2) objective, (3) clear, (4) non-inferential, and (5) relevant (e.g., visually observable). Some of these codes emerged from the data while others (e.g., distinguishing observations from inferences; using objective details) were identified in the literature (Metz, 2000; Norris, 1984).

Table 1: Codes for Sufficiency and Appropriateness in Students' Descriptions

| Category | Code | Description |
|---|---|---|
| Sufficiency | 2 | Includes 2+ details. (e.g., "It has little hooks and its round.") |
| | 1 | Includes one detail. (e.g., "It is pointy.") |
| | 0 | Includes no details |
| Appropriateness | 2 | Appropriate details. (e.g., "It has green body and red and yellow petals.") |
| | 1 | Appropriate & inappropriate details. (e.g., "Leaves are green it looks beatiful.") |
| | 0 | Inappropriate details. (e.g., "Like a very butiful flower it smells good.") |

Seven *explanations* were analyzed for each student, five from four lessons and two from the unit test. Explanation topics included the location of seeds, seed parts, seed dispersal, and requirements for plant growth. Students' explanations were analyzed based on the accuracy and completeness of claims and evidence. (See Table 2.) Accuracy was defined as information that was relevant to the lesson and scientifically correct. Completeness was defined as statements that required no inference on the part of the reader (e.g., logical connections made between ideas; pronouns defined). These codes were adapted from the literature (McNeill & Krajcik, in press; Sandoval, 2003).

Table 2: Codes for Quality of Claims and Evidence in Students' Explanations

| Category | Code | Description |
|---|---|---|
| Claims | 2 | Accurate, complete claim. (e.g., "Plants need water, sun, air.") |
| | 1 | Accurate but incomplete claim. May include inaccurate parts. (e.g., "Plants need water & food.") |
| | 0 | No claim or inaccurate claim. (e.g., "They need plant food.") |
| Evidence | 2 | Accurate, complete evidence. (e.g., "When we cut the fruit in half, there were seeds.") |
| | 1 | Accurate but incomplete evidence. May include inaccurate parts. (e.g., "I cut an apple before.") |
| | 0 | No evidence or inaccurate evidence. (e.g., "I know this no matter what.") |

## Results & Discussion

We describe the quality of the second grade students' drawings, descriptions, and explanations. To foreshadow our findings, we find that students' *drawings* sometimes failed to include accurate sizes, detail, and color. With regard to *descriptions*, the majority of students included a sufficient number of details. However, students struggled with using appropriate details, often incorporating unclear information in their descriptions. Finally, the majority of students' *explanations* included accurate and complete claims but often failed to include accurate and complete evidence.

### Students' Drawings of Their Observations

In judging the quality of students' drawings, half of the second graders (50%) satisfied at least three of the four drawing criteria, scoring on average 2.5 out of 4.0. (See Table 3.) This suggests that children were fairly successful in using drawings to record their observations. However, about half of the students (47%) struggled to draw objects to size, and nearly just as many students (40%) failed to add color to their drawings or use details in a complete and accurate way. For example, one student observed the inside of a grape, and in drawing his observations, exaggerated its size and did not add any color or draw its seeds. Overall, these results indicate that although students' drawings tended to meet several of the criteria for high-quality drawings, they still struggled with this inquiry task.

Table 3: Average Score and Percentages for Criteria Satisfied by Students' Drawings

| | # of Drawings | Score | Size | Details | Color | Shape |
|---|---|---|---|---|---|---|
| Lesson Average | 11 | 2.5 | 53% | 60% | 60% | 68% |

### Students' Descriptions of Their Observations

In addition to drawing seeds and plants, students also described seeds and plants in words. The majority of the young students (74%) included a sufficient number of details (i.e., two or more details) in their responses. (See Table 4.) For example, one student used several details to describe her sun-deprived plant, writing, "The plant is dark green and the part covered was crunchie and light green and gray." This finding suggests that students were fairly successful in using several details in their descriptions.

Table 4: Average Score and Percentages for Sufficiency in Students' Descriptions

| | # of Descriptions | Score | 0 = No details. | 1 = One detail. | 2 = 2+ details. |
|---|---|---|---|---|---|
| Unit Average | 4 | 1.7 | 6% | 21% | 74% |

Another important aspect of a scientific description is the appropriateness of details—that is, how accurate, objective, clear, non-inferential, and relevant they are. Less than half of the second graders (39%) wrote descriptions with only appropriate details. (See Table 5.) This suggests that providing appropriate details in their descriptions was a challenging task for most students. The scores for students' use of appropriate details were also consistently lower than their scores for sufficiency. This suggests that it is easier for young children to give multiple details than to use appropriate details to describe their observations.

Table 5: Average Score and Percentages for Appropriateness in Students' Descriptions

| | # of Descriptions | Score | 0 = Inappropriate details. | 1 = Appropriate & inappropriate details. | 2 = Appropriate details. |
|---|---|---|---|---|---|
| Unit Average | 4 | 1.1 | 31% | 32% | 39% |

With regard to satisfying specific criteria for appropriateness, the criterion most often left unsatisfied was clarity. (See Table 6.) Students' descriptions were often unclear due to ambiguous details and pronouns. For example, one student described her marigold as "gold on the bottom red on top," not clarifying which parts of the plant these adjectives described. In contrast, students tended to include non-inferential, objective, relevant, and accurate details. Overall, these results indicate that students met several criteria for high-quality descriptions but struggled with *clearly* describing their observations.

Table 6: Average Percentages for Criteria Satisfied in Students' Descriptions

| | # of Descriptions | Clear | Non-Inferential | Objective | Relevant | Accurate |
|---|---|---|---|---|---|---|
| Unit Average | 4 | 70% | 77% | 85% | 95% | 96% |

### Students' Explanations

Scientific explanations are claims supported by evidence. The majority of second graders (54%) stated accurate and complete claims in their explanations. (See Table 7.) Additionally, most students (88%) formed complete and accurate claims when they could state one of several possible claims, but few students (11%) gave complete, accurate claims when they had to state one specific claim with multiple parts. For example, many students struggled to form the claim, "Seeds have a seed coat, food supply, and embryo," which entails a specific answer with multiple parts. In contrast, when asked to state one thing that plants need to grow, many students successfully defended one of several possible claims, such as "Plants need water," or "Plants need sunlight." This suggests that it may be easier for children to state an accurate and complete claim if more than one type of claim is acceptable to defend rather than having to state one specific claim with multiple parts.

Table 7: Average Score and Percentages for Quality of Claims in Students' Explanations

| | # of Explanations | Score | 0 = Inaccurate claim or no claim. | 1 = Accurate but incomplete claim. | 2 = Accurate & complete claim. |
|---|---|---|---|---|---|
| Unit Average | 7 | 1.42 | 22% | 24% | 54% |

To support second graders in using their observations as evidence to back up their claims, specific questions and sentences starters were included in the worksheets, as described in the methods section. However, few children (19%) provided complete, accurate evidence in their explanations. (See Table 8.) For example, students were asked to explain *how* they knew plants needed sunlight. One student gave complete and accurate evidence in his explanation, writing, "The plants that did not get sunlight are crumbled." However, many students did not use complete evidence. For example, one child did not specify whether he was referring to the plant that received sunlight or to the one that had not, stating, "The plant does not look good." Still others made no claim at all, writing, for example, "We just talked about it in science." These results indicate that even though some students were able to use evidence to support a claim, most students still struggled with this inquiry task, despite the supports in the worksheets. Second graders' evidence scores were also consistently lower than their claim scores. This finding indicates that using evidence to support a claim may be a more challenging task for children than stating a scientific claim.

Table 8: Average Score and Percentages for Quality of Evidence in Students' Explanations

| | # of Explanations | Score | 0 = No evidence or inaccurate evidence. | 1 = Accurate but incomplete evidence. | 2 = Accurate and complete evidence. |
|---|---|---|---|---|---|
| Unit Average | 7 | 0.63 | 55% | 27% | 19% |

## Implications for the Design of Inquiry-Based Educative Curriculum Materials

Young children can participate in inquiry-based science if they are supported in this process (Metz, 2000). However, little is known about the abilities young students possess or the difficulties they face when they are engaged in recording observations and constructing scientific explanations. This research helps clarify the ways in which young children can successfully engage in these two inquiry tasks as well as the ways in which students need support. These findings may inform the ways in which educative curriculum materials can be designed to promote both elementary school teachers' and their students' learning about these inquiry practices. More specifically, worksheets that are designed to specifically address students' difficulties can promote students' learning and help them overcome the challenges that they might face (Resier, 2004). Additionally, materials can support teachers' learning by providing them with instructional approaches and rationales to understand why certain approaches are appropriate (Ball & Cohen, 1996; Davis & Krajcik, 2005).

This study was our first investigation into how educative curriculum materials might support early elementary students' learning with regard to recoding observations and constructing evidence-based explanations. Though we provided *general* prompts for recording observations and *specific* supports for constructing explanations in the curriculum materials, we learned that there is room for improvement to better support these students' learning as well as their teachers' learning about these two inquiry practices.

Little is known about the ways in which students make scientific observations and thus minimal supports for students were provided in the curriculum materials with regard to this inquiry practice. In using these materials, the second graders in this study formed adequate drawings of their physical observations, but they struggled to include accurate sizes, detail, and color in their drawings. To encourage students to use accurate sizes, curricula could be designed with sufficiently large blank spaces to enable students to draw objects to size. Materials could also help students use detail in their drawings by asking students to use labels to draw attention to specific parts of their pictures. As for teacher supports, educative curriculum materials could provide teachers with a checklist of drawing criteria along with descriptions of each criterion. This support would make explicit the expectations for students' drawings and encourage teachers to model the use of these criteria for their students. The materials could also explain to teachers the importance of this instructional approach, in that students often have trouble drawing their observations and need help with specific aspects of this process.

In describing their observations, the second graders provided a sufficient number of details in their descriptions but often included unclear details. To help young students make clear descriptions, curriculum materials could first ask students, "What part are you looking at?" before prompting students to describe what they actually see. This prompt might help students connect their details to specific features of objects rather than leaving pronouns undefined. To further help students use appropriate details, materials could use the drawing criteria (e.g., size, shape, color, details) to describe the kinds of details students might provide in their descriptions (see Norris, 1984, for a list of conditions for making good observations). Curricula might also have students describe their observations in words before using pictures, so students can use their descriptions as a guide for making drawings of their observations. To support teachers' learning, educative curriculum materials could include a list of description criteria and lesson-specific examples to make teachers cognizant of the implicit criteria for making scientific observations. The rationale for using this approach could also be emphasized, explaining that students often include inappropriate details in their descriptions and need help in distinguishing appropriate details from inappropriate information.

Finally, with regard to constructing explanations, most students included accurate and complete claims, specifically when students had the option to state one of many possible claims rather than having to state one specific claim. However, many students had trouble using accurate and complete evidence to support their claims (see McNeill & Krajcik, in press, for a similar finding with older students). In providing direct supports for students' learning, worksheets could ask young children to choose a scientific claim from a list of options (building on Bell, 2004) so students do not have to come up with a claim all on their own that may not even be defensible. Curriculum materials could also help students use their observations as evidence by prompting students to directly use their drawings and descriptions to explain "how they know" their claim is correct (see Herrenkohl & Guerra, 1998, for a similar approach in having students relate evidence to a claim). To assist teachers in thinking about this inquiry practice, educative curriculum materials could also include examples of student responses to enable teachers to more clearly visualize what an explanation might look like for a particular lesson and to anticipate the kinds of answers students might give. The rationale behind these instructional approaches could also be given, explaining that even young children can construct evidence-based explanations but that they sometimes need help with the evidence-use aspect of this task.

This study emphasizes the need for researchers to design educative curriculum materials with specific supports for young children engaged in recording observations and constructing scientific explanations. These materials will need to be developed through an iterative process of testing and refinement to further clarify how young students need help and how particular scaffolding can support both students' and teachers' learning about these inquiry practices. Future research also needs to determine how applicable these findings are to other age groups, including younger early elementary students and upper elementary students. Finally, other forms of support need to be developed and used in conjunction with educative curriculum materials in order to allow these materials to be used most effectively by teachers. In these ways, future research will help us gain a better understanding of the kinds of observations and explanations early elementary school students can make and the ways in which curriculum materials can support students and teachers in learning about these inquiry practices.

## References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Ball, D.L. & Cohen, D.K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher, 25*(9), 6-8, 14.

Bell, P. (2004). Promoting students' argument construction and collaborative debate in the science classroom. In M. C. Linn, E. A. Davis, & P. Bell (Eds.), *Internet Environments for Science Education* (pp. 115-143). Mahwah, NJ: Lawrence Erlbaum Associates.

Davis, E.A. & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3-14.

Davis, E. A., Smithey, J., & Petish, D. (2004). Designing an online learning environment for new elementary science teachers: Supports for learning to teach. In Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon & F. Herrera (Eds.), *Proceedings of the 6th International Conference of the Learning Sciences, ICLS2004* (pp. 594). Mahwah, NJ: Lawrence Erlbaum Assoc.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom.. *Educational Researcher, 23*(7), 5-12.

Driver, R., Newton, P. & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*. *84*(3), 287-312.

Herrenkohl, L. R., Guerra, M. R. (1998). Participant structures, scientific discourse, and student engagement in fourth grade. *Cognition and Instruction, 16*(4), 431-473.

Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for

inquiry in science classrooms. In J. Minstrell & E.H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283-315). Washington D.C.: AAAS.
Kuhn, D. (1993) Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77,* 319-338.
Lehrer, R. & Schauble, L. (1998). Reasoning about structure and function: Children's conceptions of gears. *Journal of Research in Science Teaching, 35*(1), 3-25.
Metz, K. E. (2000). Young children's inquiry in biology: Building the knowledge bases to empower independent inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 371-404). Washington, DC: AAAS.
McNeill, K. L. & Krajcik, J. (in press). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett & P. Shah (Eds.) *Thinking with data: the Proceedings of the 33rd Carnegie Symposium on Cognition*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, D.C.: National Academy Press.
Norris, S.P. (1984). Defining observational competence. *Science Education, 68*(2), 129-142.
Reiser, B. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*(3), 273-304.
Sandoval, W. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of the Learning Sciences, 12*(1), 5-51.
Toulmin, S. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.

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