

**An Analysis of Notebook Writing
in Elementary Science Classrooms**

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Abstract

Journal or notebook writing is viewed as a critical aspect of science teaching and learning because of its potential to inform the former and assess the latter (National Research Council, 1996; Shepardson & Britsch, 1997). Nevertheless, little is known about the relationship between the contents of student science notebooks and the classroom contexts in which they are used. This study examines the use of notebooks in three fifth-grade classrooms during a unit on electric circuits. Our purpose is to ascertain the extent to which notebooks might serve as a tool for monitoring teaching and learning. Analyses of classroom contexts indicated that teachers promoted notebook writing through explicit instructions and prompts, provided frequent opportunities for students to write, and attended to student documentation of the procedural aspects of the investigations. Consistent with these classroom observations, students' science notebooks contained records of teacher-dictated purposes and procedures and student-generated observations for each investigation. Other significant aspects of student performance and observed classroom practice were not documented in the notebooks; these included records of problem-solving strategies, discussions of task-related concepts, and references to variations in problem solutions across student groups. Implications of notebooks as a tool for monitoring science instruction and assessing student learning are discussed.

Writing has become increasingly popular in science education. "Indeed, the whole notion of maintaining throughout a course a 'learning log,' . . . is indebted to

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the empiricist's habit of collecting information and conjectures; suspending premature closure; and committing oneself to formal argument only when all evidence is collected and all explanations have been entertained" (Connolly, 1989, p. 7). Incorporating these and other habitudes of scientists into classroom instruction is intended to promote a genuine appreciation of the "intellectual and cultural traditions that characterize the practice of contemporary science" (National Research Council, 1996, p. 19).

Consistent with this perspective, the conduct of scientific inquiry is viewed as a key strategy for developing students' understanding of ideas and concepts. Important here is a written record of one's efforts that can be used to formulate questions, shape investigations, monitor progress toward goals, and generate conclusions. In this regard, students in the course of an instructional unit carry out a sequence of investigations using relevant materials and tools, document their efforts and outcomes in a science notebook, and debate discrepant findings with their classmates. As the primary facilitator of this process, the teacher is positioned to influence these and other aspects of science instruction. The nature and extent of this influence conditions the viability of notebooks as a tool for teaching, learning, and assessment.

This study profiles notebook use in three fifth-grade classrooms where "hands-on" instruction provides students the opportunity to learn by doing science and writing about it. Explicit guidelines for recording in science notebooks are not prescribed by the district science program. Rather, the structure, content, quantity, and quality of students' notebook entries are a reflection of teacher practice. As such, an examination of student notebook entries would be incomplete without consideration of the teaching and learning environments in which they are used. For our purpose, we consider two critical features of the classroom context that influence student notebook entries: the nature of science instruction and the teacher's role in facilitating notebook use. Of particular concern are the ways the teacher organizes science writing, the kinds of opportunities available for writing, and the attention or feedback given to student writing observed across a set of instructional activities. In this paper we describe the ways in which the teachers facilitate notebook writing as a part of an inquiry of electric circuits, and we compare these classroom observations with the structure and content of students' science notebooks. Implications of notebooks as a tool for monitoring science instruction and assessing student learning are discussed.

Classroom Context

Science education is designed, in part, to promote an understanding of the ways in which scientists study the natural world. From this perspective, an instructional unit in elementary science classrooms can be conceived as an inquiry around a particular topic. For example, a unit on electric circuits can be viewed as an inquiry that begins with the general questions “What is a circuit?” and “What is the impact of changing various components in circuits of different configurations?” Given these key guiding questions for the unit, each of the lessons or investigations described in the curriculum guide can be viewed as a set of related inquiries. For each, students might conduct an investigation with a specific purpose or question (e.g., What are the critical contact points on a bulb or battery? What is the impact of adding bulbs to a circuit in series or parallel?), collect data to answer the key question(s) using relevant procedures, and then formulate answers (conclusions) to the question based on the data collected. The accumulation and synthesis of information and evidence across all of the individual investigations or inquiries can be used to generate explanations, explore the central topic of the unit, in this case circuits, and suggest questions for further study.

It is expected that in teaching kit-based curricular units, teachers will formulate the unit as an inquiry (i.e., unit purpose, sequence of activities or investigations each with its own purpose, procedures, results and conclusion, and unit summary or conclusions). In elementary science classrooms, inquiry can involve some combination of teacher guidance and student self-direction. As responsibility for the various aspects of inquiry shifts from teacher to student, the nature of the inquiry shifts along a continuum from guided to open (National Research Council, 2000). The appropriateness and merit of highly structured investigations, wherein a question is posed to students and they are given a set of procedures to follow to answer the question. (i.e., guided), versus investigations in which students pose questions, design investigations, and communicate their findings (i.e., open) is dependent, in part, on the goals for learning. Additionally, the way in which the lessons of the unit are presented and carried out will necessarily vary as a function of teachers’ knowledge and experience with the subject matter (cf. Shulman, 1986). Teachers less familiar with the traditions of inquiry or less practiced in science teaching may, for example, view the investigations comprising a science curricular unit as a set of independent confirmatory exercises. The way in which the teacher

interprets the unit will be reflected in the structure and contents of students' science notebooks.

The purpose of writing in science as conveyed by the teacher also influences the quantity, quality, and organization of students' notebook entries. Consider a distinction between writing for the purpose of generating a record of science experiences and writing for the purpose of developing conceptual understanding (e.g., Shepardson & Britsch, 1997). In the first instance, notebooks might be expected to contain descriptions of what was done, how it was done, and what resulted or was found. In contrast, notebook writing that serves as a process through which students, like traditional empiricists, make sense of their investigations in the immediate and broader context would engender a very different structure. These notebooks may, for example, begin with a stated purpose or question. Next would come a written record of investigations for which students include a rationale for their plan or approach, a set of procedures or strategies used to address a particular question, and a coherent explanation for their findings backed by necessary and sufficient evidence. Inquiry records of this sort may be annotated with reflections on work completed to date, questions that remain unanswered, ideas for future research, or other relevant comments. These notebooks may end with a unit summary or a set of conclusions based on a review and compilation of relevant information from the sequence of completed investigations.

This relative emphasis on writing to document what was done and produced in science class (i.e., product) versus writing as a way of thinking about and learning science (i.e., process) is expected to influence the integration of writing with the conduct of science inquiry. Further, the importance of writing as an essential component of science inquiry can be supported or tempered by the teacher's attention to various aspects of writing. For example, monitoring of activity completion versus monitoring of understanding of what was done signals for students the relative value of doing over learning. Likewise feedback consistently focused on structural or organizational aspects of record keeping such as spelling, labeling, or tracking dates diverts attention from the questioning, reasoning, and hypothesizing central to inquiry.

In the following sections we examine the correspondence between the structure and content of students' science notebooks and the classroom contexts in which they are used. Of note here are the ways in which the teacher organizes writing, the timing and frequency of classroom opportunities to write, the nature of prompts and

scaffolding provided to support writing, and the particular aspects of notebook writing that teachers attend to via feedback or monitoring of student writing and its uses (Blumenfeld, 1992; Doyle, 1983; Rivard, 1994). Congruence between relevant instructional opportunities and notebook entries justifies consideration of notebooks as a tool for monitoring science instruction and assessing student learning.

Method

Data were collected from 83 students in three classrooms in an urban school district characterized by ethnic, economic, and language diversity. All students in the school district, as part of a K-6 hands-on science program, are taught four science units covering a range of topics. For each curricular unit, students work in groups of four to carry out a sequence of related investigations using appropriate science procedures and relevant equipment and tools. As part of “doing science,” students are expected to document their efforts and outcomes in a science notebook delivered to the schools with the science kits. This study examined students’ notebooks during the last of the four units taught in fifth grade, called “Circuits and Pathways” (Education Development Center, 1997).

Curriculum

“Circuits and Pathways” is an 8- to 10-week kit-based curricular unit in which students investigate the questions “What is a circuit?” and “What is the impact of changing various components (i.e., bulbs, batteries, fuses) in a circuit configured in different ways (i.e., series or parallel)?” The unit begins with an introductory lesson in which students reflect on their prior knowledge and generate questions they would like to answer about circuits. Next, the students engage in a sequence of 10 activities or investigations. The first five investigations are designed to focus students’ attention on the characteristics of a circuit. To this end, students connect batteries and bulbs in various ways to make a bulb light. As they note successful and unsuccessful configurations they begin to formulate an understanding of the critical contact points on batteries and bulbs, the concept of polarity, the kinds of materials that conduct electricity, and other important considerations in constructing a circuit. Following this, students complete an assessment in which they are presented with a number of circuit drawings, and for each, they are asked to predict if the bulb in circuit would light or not light. The students then construct the illustrated circuits and compare their prediction to what is observed.

The remaining five investigations are designed to build on students' understanding of a circuit (series and parallel) through comparative investigations of the effect of changing combinations of circuit components on bulb brightness (e.g., number of batteries, number of bulbs, inclusion of switches or fuses). Comparing bulb brightness in different circuits requires a standard measure of brightness. For this purpose, students make a "brightness meter" by combining strips of increasingly thick layers of paper with which they can judge relative bulb brightness. If a bulb in circuit "shines" through 10 layers of paper, then the bulb is relatively bright. In contrast, a bulb in circuit that can be seen only through one layer of paper is relatively dim. The unit concludes with a problem-solving activity. Students are asked to apply their knowledge of circuits to identify six "hidden circuits" enclosed in a Manila folder. For this purpose, they connect circuits to brass fasteners on the outside of the folder, and on the basis of bulb brightness, determine the circuit configurations inside the folder.

Materials to complete each of the aforementioned investigations are delivered to the classrooms in a science kit. Included with the materials is an instructional manual. The manual provides a description of each of the lessons or learning activities, including a general overview of the lesson, goals for learning, materials the teacher might need to prepare prior to instruction, a list of materials needed to complete the investigation, and student worksheets for recording what was done and what was learned. Also included in the manual is a section on relevant science background knowledge and a list of books and audio-visual aids that can serve as appropriate reference materials or sources of additional information for teachers and students.

Teachers

The three participating teachers had 10 or more years of elementary teaching experience, the last five of which involved hands-on science. The district provided extensive professional development opportunities to support the implementation and use of kit-based curricula in their classrooms. Summer workshops focused on key features of hands-on science instruction including the purpose of the unit, materials management, grouping strategies, and the use of notebooks. During the first two academic years in which teachers taught the units, science resource staff provided regular in-class support. In subsequent years, classroom visits and other

instructional resources such as books or models have been available upon request from the district science resource center.

Data Collection

Two types of data were collected: classroom observations and students' science notebooks. For the observations, three teachers participating in a larger study of cognition, motivation, and beliefs were contacted and asked if they would like to participate in this part of the study. Each was given a stipend at the completion of the study. During the final quarter of the school year, a member of the research team visited the 3 fifth-grade classrooms and videotaped a sample of science activities carried out as part of the "Circuits and Pathways" unit (see Table 1).

Table 1
Summary of Data Collected

"Circuits and Pathways" unit	Teacher A		Teacher B		Teacher C	
	Observe lesson ^a	Notebook entry ^b	Observe lesson ^a	Notebook entry ^b	Observe lesson ^a	Notebook entry ^b
Unit introduction	X	X			X	X
Sequence of investigations						
1. Motor	X	X		X	X	X
2. Lighting the bulb	X	X		X	X	X
3. What's inside the bulb		X		X		X
4. Conductor/nonconductor		X		X		X
<i>Embedded assessment</i>		X	X			X
5. Series circuits	X	X	X	X	X	X
6. Brightness meters			X	X	X	X
7. Parallel circuits	X	X	X	X	X	X
8. Electric resistance	X	X	X	X		X
9. Switches	X	X	X	X	X	X
10. Fuses			X	X	X	X
Unit Summary/Conclusions						
<i>Hidden circuits assessment</i>					X	X

^a Observe lesson: X indicates classroom activities that were observed and videotaped.

^b Notebook entry: X indicates at least one student had a notebook entry for this classroom activity.

Science typically is taught for 50 minutes, one to three times per week for nine weeks. At the discretion of the teacher, the lessons can be shortened, extended, or combined. A total of 7, 7, and 8 lessons were observed for Teachers A, B, and C, respectively (see Table 1). Some of the lessons were taught over several class periods, and on occasion, teachers extended a science class beyond the typical 50 minutes to 60 or 90 minutes. After completing the unit, teachers collected and submitted students' notebooks for evaluation. The notebooks were photocopied and returned to the students before the end of the school year. Eighty-three notebooks were collected from the three classrooms ($n_{\text{notebooks}} = 20, 31, \text{ and } 32$ for classes A, B, and C, respectively).²

Analysis

Classroom Observations

Analysis of videotaped classroom observations was carried out in four steps. First, the 24 videotapes were viewed, and about one half of them were transcribed verbatim. For the remaining tapes, brief summaries of the observations were compiled to accompany verbatim transcriptions of relevant scenes and/or lines of dialog (e.g., instances of teachers checking that students were writing in their notebooks, teachers' instructions to students about what to record in their notebooks).

Second, lines of transcript data were entered into FolioVIEWS, a Hypertext database management system, and particular features of classroom practice were highlighted. These included (a) the teacher's stated purpose for notebook writing and how the teacher introduced writing during science instruction (i.e., organization); (b) the frequency and nature of teacher-dictated or student-generated writing (i.e., opportunities); and (c) the attention or feedback given to various aspects of writing (i.e., form versus substance), or prompts to consult notebooks to remind students of what they did and what they found out (attention). Each highlighted piece of text was preceded by a code indicating the teacher (A, B, or C), transcript (observations 1 through 9), and record number (instances 1 through n), which refers to sequence in which the instance occurred. For example, A8.18 refers to Teacher A, observation 8, and instance 18 during the 8th observation.

² Teacher A inadvertently sent notebooks home with nine students.

Third, highlighted text from each of the classroom observations was consolidated into a 3 x 4 matrix—teachers’ role in notebook writing (organization, opportunities, and attention) by phase of inquiry (purpose, procedures, observations or results, and conclusions). These 24 classroom observation matrices ($n = 9, 6,$ and 9 for Teachers A, B, and C, respectively) were reduced to three teacher summary matrices. Each teacher summary matrix contained a set of general statements for each of the 12 cells (3 teachers’ role x 4 phase of inquiry). For example, a summary statement describing attention to notebook writing during the purpose phase of inquiry for a given teacher might read: “The teacher requires students to record their purpose and prediction in their notebooks before they begin their investigation (A4.14, A7.21, A9.06).” The codes refer to the instances where this interaction between teacher role and phase of inquiry was observed. A4.14 refers to Teacher A, the 4th observation, and the 14th instance of attention to notebook writing.

Fourth, the teacher summary matrices were reviewed and the relationship between phase of inquiry and organization, opportunity, and attention were identified across classrooms. Between-teacher similarities and differences were highlighted so as to characterize notebook use in elementary classrooms. Our purpose is not to compare teachers but to point out the ways in which notebooks are incorporated into science instruction and to consider the implications of this practice for teaching, learning, and assessment.

Science Notebooks

To characterize the structure and content of notebook entries for the “Circuits and Pathways” unit, students’ notebook entries were read, noting the presence and nature of general features of inquiry. Did student notebooks have (a) an introduction or purpose for the unit (e.g., title, statement of what is going to be studied), (b) an inquiry structure for each of the 10 lessons in the unit (i.e., purpose, procedures, observations/results, and conclusions), and (c) a summary statement of what was learned or a concluding statement related to the purpose of the unit (i.e., what I know about circuits)? Answers to these questions suggest the ways in which the teacher interprets the unit (e.g., science inquiry versus confirmatory science), the nature of inquiry when present (teacher or student directed), and the purpose of writing in science as conveyed by the teacher (e.g., process versus product).

In addition to evidence of the nature of science instruction and the purpose of writing in science, we considered the presence of teacher feedback and evaluative or

affective statements as evidence that teachers and/or students used writing to assess knowledge or understanding of circuits. Finally, we noted various organizational features of the notebooks such as the presence of titles, page numbers, or date of entry and the relative consistency with which we observed these structural aspects of entries versus substantive aspects such as explanations of findings or questions for further investigation.

Results and Discussion

Our goal here is to characterize the ways in which teachers shape the form and function of writing in science. For our purposes we consider three observable aspects of the teacher's role in facilitating notebook writing as part of science inquiry. These are (a) *organization* of notebook writing, (b) *opportunities* for writing, and (c) *attention* to writing. We considered each of these aspects by phase of inquiry. For example, was notebook writing organized (i.e., introduced, presented) as a tool to aid thinking during inquiry, or was notebook writing organized in ways that suggest the primary function of writing is to document what was done in science class? Did teachers provide opportunities for students to write during all phases of inquiry, or was writing a prominent feature of some phases (e.g., observations) but not others (e.g., conclusions)? Did teachers provide a structure for notebook entries, or were students responsible for deciding what and how to record various aspects of their investigations? Did teachers provide feedback on the quality of notebook entries, or did the teachers simply check that students recorded some information for each investigation?

Questions of this sort guided our analysis of notebook use in the three elementary science classrooms we observed. In what follows, we provide a general description of the instructional context. Then, for each phase of inquiry, we describe the nature of science instruction (i.e., guided versus open inquiry), the ways in which notebook writing was organized, the frequency and nature of opportunities for writing, and the attention and feedback teachers gave to notebook writing. Following this we examine the correspondence between observed classroom practice and the structure and contents of students' notebooks.

Classroom Observations

Instructional context. The "Circuits and Pathways" unit, as described in the curriculum guide, begins with an introduction to the unit, followed by five

investigations, an embedded assessment, five additional investigations, and a concluding assessment. In the three classrooms we observed, teachers generally followed the sequence outlined in the curriculum guide. Although we observed only about 60% of the science lessons, an examination of the notebook entries suggests that teachers and students completed at least 80% of the lessons described in the curriculum guide (see Table 1). Evidence from observations and notebooks indicates that only the most experienced of the three teachers completed all the lessons (introduction, 10 investigations, embedded and end-of-unit assessments) as described in the instructional manual.

Typically, teachers spent one class period introducing the unit by helping students think about and share their prior knowledge of, and experiences with, electricity and circuits. During this time, students generated a list of questions that they wanted to pursue during the unit. Following the introduction to the unit, teachers guided students through a sequence of 10 investigations. As observed, teachers began each of the 10 investigations by reviewing the previous day's events, introducing the concept that students would be studying that day, and detailing the procedures that students would carry out. Then, students worked in groups of four to carry out their investigation, make observations, and record the results of their tests. Following this group work, teachers led a whole-class discussion to conclude the activity or investigation for that day. After the completion of the initial set of five investigations, students were given 12 circuit diagrams and asked to predict for each if the bulb in the circuit would light. Then students were asked to construct the circuits and comment on discrepancies between what they predicted would happen and the results of their tests. Following the embedded assessment, students then proceeded, as noted above, to complete five additional investigations. Having completed all 10 investigations that comprised the unit, students were asked to apply their knowledge of circuits acquired during the course of their investigations to solve a circuits problem. This final activity served as an assessment of what had been learned in the unit.

Phases of inquiry. Review of the videotaped observations indicated that notebook use was a prominent feature of science instruction. All phases of inquiry were observed with little variation among teachers in terms of focus (content versus process) and structure (teacher-directed versus student self-directed). However, the ways in which notebook writing was organized and used, the timing and frequency of classroom opportunities to write, the nature of prompts and structures (i.e.,

worksheets, tables) provided to support writing, and the particular aspects of notebook use that teachers attended to via feedback or monitoring of student writing varied by the phase of inquiry. In what follows we describe notebook use by phase of inquiry.

Unit introduction. As part of the introduction to the “Circuits and Pathways” unit, teachers engaged their students in a brainstorming activity to elicit their prior knowledge of circuits (e.g., “What do you know?” and “What do you think you know?”). Teachers also solicited from students the questions they wanted to answer about circuits (e.g., “What do you want to know?”). Students, as instructed, compiled a chart in their notebooks and then shared their charts as a class. The purpose of this introductory activity was to provide a context for the upcoming investigations, acknowledge students’ current understanding of circuits, and create a reference for changes in their ideas, conceptions, and hypotheses about circuits as they proceeded with the unit.

During the introduction to the unit, teachers also reviewed the materials students would be working with (e.g., batteries, bulb holders) and the structure or routine for doing science that was established with previous instructional units. Attention was drawn to the role of notebooks for keeping a record of what was done. For example, Teacher C reminded students of the format or structure notebook entries should take:

Whenever we are going to be doing our science now, each day I will have something on the board like this. It will tell you, you are going to put the date, some have already copied that down. I will list the materials that you will use that day. ... Anyway, you are required to put this in your journal before we begin, and then the challenge. Remember we had this when we were working mostly with our daytime astronomy, remember, we had this format. So, we are putting down what it is that the lesson is about, what we are trying to figure out, find out, discover on that particular day.

Teacher A used the introduction to the unit to remind students of the purposes of notebook writing in science class. In particular she distinguished between the purpose of notebook writing for students (record of what was done) and the purpose of student notebook writing for teachers (indicator of what was learned):

Teacher A: You are going to have to write down what you discover; it’s very important that you document your work. Because why?

Student: We can forget.

Teacher A: Because you can forget. And what else? For other people, like for (points to teacher's aide) or I who will be giving you grades about how well you are doing science, we want to read about and say: Does the child understand what they are doing? Did they find out what they are supposed to figure out from this experiment? Of course you might find out other things from an experiment, too. Or you might find out other things by making mistakes in your original experiment. But we need to know. Are you discovering what should happen or what will happen? I need to know.

In summary, the unit introduction was used to generate ideas and questions that could form the basis for subsequent investigations in an inquiry-oriented learning environment. Teachers encouraged students to think about related experiences and reviewed with students the standard procedures and established rules of conduct for science class. Specific learning goals—What is a circuit and what is the impact of changing various components in a circuit configured in different ways?—were not discussed. Rather the unit was presented, during the introductory lesson, as an open-ended inquiry that begins by acknowledging what students already know and formulating what they want to know about circuits. Of note is the explicit emphasis on writing in science. During this phase, teachers reminded students of the purpose of writing in notebooks, gave students the opportunity to record their ideas, and provided a structure for doing so. Having students share their entries with the other members of the class provided a way for teachers to monitor that notebook writing took place, and this sharing activity also served to reinforce the use of notebook writing in science.

Sequence of related investigations. Teachers generally began each of the 10 investigations by reviewing the previous day's events, introducing the concept that students would be studying that day, and detailing the procedures that students would carry out. Approximately 10 minutes of each 50-minute science lesson were devoted to introducing science concepts and prompting students to think about them in terms of other experiences they may have had. Teachers used a variety of strategies for this purpose. For example, Teacher C introduced a lesson on the impact of a switch in circuit with one or more batteries and bulbs by engaging students in a discussion about where switches are found in their home and the function of a switch (i.e., it breaks or opens a circuit). Teacher A had students enact various concepts. For example, to promote a comparison of series and parallel circuits, Teacher A had students come to the front of the class and arrange themselves (by holding hands) to show the differences between series and parallel circuits. Much of the introduction to each of the activities in the unit was focused on

conceptual understanding, but as described below, this focus was not maintained throughout subsequent phases of inquiry.

Investigation purpose. In two of the three classes, teachers began the day's activities by requiring students to write in their notebooks the purpose of the investigation, list of materials, and sequence of procedures. In one of the classes, the teacher stated the purpose of the activity after a review of the previous day's work but without specific instructions to students to write this information in their notebooks. The purpose of each investigation was presented in the form of a question ("What will happen if you add another battery [to a series circuit]? Another bulb?"), or challenge ("Try to wire circuits with more than one bulb."). Emphasis was placed on what students were going to do (e.g., build something) rather than what they were trying to find out (e.g., explore the effect of a particular variable on bulb brightness). This relative emphasis on the procedural aspects of the activity stands in contrast to the conceptual focus of the introduction to the activity described above.

Following the initial recording of the purpose for the day's activity (or a discussion of the purpose without writing as was the case for Teacher B), teachers generally outlined a structure for data recording. Teacher A provided a model of labeled diagrams and partially completed data tables to guide students' observations and data recording: "Okay, you need to put a line on your paper...split it in halves in order to draw both what makes the bulb light and what doesn't." Likewise, Teachers B and C gave explicit directions on the format for recording data or provided a structured worksheet for this purpose. The teacher directions for data recording helped clarify for students the purpose of the activity, suggested strategies for beginning their inquiry, and established some boundaries so students could proceed without further direction (cf. Doris, 1991). Following these instructions for data recording, students collected the relevant materials (e.g., batteries, bulbs, wire) and began their investigations.

Observations/results. Approximately 30 minutes of each 50-minute science class were allotted to students to work in groups of four to carry out the investigations. During this phase, students were encouraged to consult their notebooks to answer their queries about what to do or how to do it. For example, when a student indicated that he could not get the bulb to light, Teacher B responded: "Then look in your notebook and see what did you do to turn on a light. . . . If you did it before and you took good notes about it, you should be able to do it

now.” Likewise, when another student asked, “How do you make a parallel circuit?” Teacher B responded by referring the student to her notebook, saying: “If you don’t remember how to do a parallel circuit, look in your book where you diagrammed a parallel circuit. What do you see that’s different?” In this way, teachers reinforced some purposes of notebook writing. Notebook entries can remind students of strategies that were successful in achieving particular goals such as circuit configurations that resulted in the bulb lighting. Alternatively, they can serve a trouble-shooting purpose. That is, students can compare one circuit configuration with another to determine why the expected result (i.e., bulb lighting brightly) was not realized.

Teacher directions were kept to a minimum during the observation/results phase in contrast to the explicit instructions on what and how to record that were observed when teachers described the purpose of each activity. During the observations/results phase, students generally recorded data on their own and in their own words. As noted above, teachers provided the structure for this purpose. Teachers monitored student notebook use closely during this phase, prompting students frequently to record what they were doing and finding out. Typically, teacher comments consisted of asking students to make some minor corrections to their notebook recordings (e.g., label drawings, correct spelling), or reminders to write down their observations. As students conducted their investigations, teachers would circulate from group to group to answer questions, clarify the procedures, and remedy “equipment” problems as in the following exchange:

Teacher C (to Group A): Did you have something to work here? And you wrote it down? Make sure you draw everything whether it works or not.

(To Group B): OK, draw the way you put it together and indicate that it worked.

(To Group C): Write down that you put one on the side and one on the end. Put it down that it worked.

(To Group D): Draw a picture to show what your connection is.

In summary, teachers structured the notebook entries for the observations/results phase of each investigation or inquiry. This structure helped students organize their entries so they could concentrate their time and effort on conducting the investigation. Having all of the students use the same format for data entry facilitated teacher monitoring of student work as teachers circulated around their classrooms of 30 students. Teachers’ frequent monitoring of notebook writing

during this phase signaled the importance of documenting what was done and what was discovered. Teacher prompts to consider previous notebook entries to aid with the current investigation served to remind students of the notebook's purpose and potential usefulness.

Investigation conclusion. Following this group work, teachers led a discussion with the whole class to conclude the activity or investigation. This discussion took various forms and was always accompanied by teacher requests for students to write in their notebooks. For example, Teacher A prompted students to refer to their notebooks as they reported their data to the class. Student discussions were recorded on the board, and then students were given an opportunity to write in their notebooks. "Having students share their explanations provides others the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations" (National Research Council, 2000, p. 27).

When students were asked to write in their notebooks during the conclusion phase, teachers provided a focus or guide for this purpose. For example, Teacher B asked students to "please write what it is that you discovered using your brightness meters as a further explanation of the difference between a series circuit and a parallel circuit." For some investigations, teachers gave students a summary statement to complete such as: "If the batteries stay the same and the number of bulbs increases . . ." Or they provided students with a series of prompts to help them draw conclusions. For example, following an activity on resistance, Teacher A asked students to respond to the following: "The (greater, lesser) the distance [length of wire connecting the battery to the bulb], the brighter the bulb. What is resistance? How would you describe it to a friend?" She termed this assignment a "quick write" and told students that they would have 10 minutes to record their thoughts in their notebooks.

During the conclusion phase of each investigation, teachers gave students time to write. As described above, the teacher prompted much of the writing through the use of targeted questions to which the students were asked to respond. Opportunities for students to generate conclusions based on their own reflections on what they had done or what they had learned were not observed. On occasion, teachers had students share their results with the class, and students were encouraged to refer to their notebooks for this purpose. More typically, the class ended before students completed their writing. Consequently, notebook recording

during the important conclusion phase of each investigation did not benefit from in-class teacher feedback on the form or substance of what was written.

Unit conclusion/summary. As described in the curricular guide, the unit was to conclude with an assessment. Students were asked to solve a problem (identify hidden circuits) through application of their knowledge of circuits acquired during the course of the just-completed sequence of investigations. Only one teacher had her students complete the concluding assessment activity. This assessment was presented as just one more activity in the unit and not as an occasion for public reflection on, and discussion about, what had been learned about circuits. Due to time constraints in the other two classrooms, the unit ended with the last investigation completed (switches for Teacher A and fuses for Teacher B; see Table 1).

It is worth noting that the curriculum guide does not include a formal concluding activity outside of the culminating assessment described above. However, we anticipated that teachers might take time to review the unit with the students, to make clear what was learned, and to reflect on how their current understandings related to the questions and ideas generated during the introduction to the unit. Classroom observations indicate that, contrary to our expectations, the unit ended without opportunities for making connections across activities, reviewing questions and ideas generated at the beginning of the unit, or contemplation of issues requiring further study.

Content of Science Notebooks

The quantity and quality of notebook entries echo the relative emphasis placed on recording procedures and data observed during the science activities. As noted in the classroom observations, students were provided with numerous opportunities for notebook writing. However, these opportunities were, for the most part, teacher directed and revolved around completing the investigation as instructed. A structure generally was provided for notebook recording, and teacher feedback typically focused on organizational features of notebook entries such as dates, labels, and spelling. Teachers monitored student writing frequently during the results/observations phases but less so during the other phases. The teacher-directed inquiry that we observed provided little in-class opportunity for students to reflect on what was learned, consider implications of information and evidence across investigations, or to generate questions for further study. As such, we might

expect the notebooks to contain a record of what was done with little variation in the structure and content of notebooks across students within a class.

In what follows we describe the contents of students' science notebooks. Recall the structure of the unit as described in the curriculum guide. The unit was to begin with an introduction followed by a sequence of five investigations, an embedded assessment, five additional investigations, and a concluding assessment. In examining student notebooks, we made distinctions among the three types of entries: introduction/conclusion, 10 inquiry investigations, two assessments. Our analysis of notebook entries focuses on the general structure of the notebooks (i.e., presence and format of each type of entry); the presence, content, and quality of information for each phase of inquiry for each of the 10 investigations; and evidence of notebook use for assessment (i.e., presence of teacher feedback or student comments). The goal here is to characterize the form and function of notebooks and to point out the extent to which notebook entries reflect classroom practice as observed. We begin with a general description of the notebooks, followed by an analysis of each type of entry, and conclude with a comparison of notebook entries to classroom observations.

Notebook entries. An examination of students' notebooks suggests that the unit was taught in the sequence described in the curriculum guide. Notebooks typically began with an introduction to the unit (except in Teacher B's class, in which they began with the first inquiry investigation), followed by a sequence of investigations. Students did record in their notebooks for each of the inquiry investigations that were taught. However, there was considerable variation across classrooms in the presence of purposes, procedures, and conclusions, and the frequency of complete entries for these investigations (see Table 2). A complete entry would include, at a minimum, a purpose, set of procedures, observations/results, and conclusions. The most consistent feature of notebooks across classrooms was a record of observations/results for each investigation, an aspect noted in the section on classroom observations, that teachers monitored closely.

When present, the notebook entries for each inquiry investigation had much the same structure. Typically, the page was headed with a title sometimes specific to the activity (e.g., motors) and sometimes more general (e.g., batteries and bulbs). Entries often were dated and then followed by a teacher-dictated purpose or challenge for the day and procedures (except class B), student-generated results/observations, and on occasion, a concluding comment or summary

Table 2
 Percentages of Notebook Contents by Teacher

Contents of notebooks	Total (<i>N</i> = 83)	Teacher A (<i>n</i> = 20 _{students})	Teacher B (<i>n</i> = 31 _{students})	Teacher C (<i>n</i> = 32 _{students})
Unit introduction	55.0	85.0	00.0	93.8
Inquiry investigations conducted	93.3	80.0	100.0	100.0
Title	32.9	63.0	12.5	35.5
Date	33.3	31.3	14.0	51.3
Purpose	42.9	36.0	00.0	83.8
Procedures	43.1	23.1	07.9	83.8
Observations/Results	85.6	70.0	96.4	84.1
Conclusions	41.3	33.1	57.0	28.4
Complete entry	12.5	07.5	00.0	25.9
Unit summary	00.0	00.0	00.0	00.0
Assessment activities completed	66.7	50.0	50.0	100.0
Teacher feedback	11.5	12.3	06.1	15.1
Student reflection or self-evaluation	01.4	05.9	00.0	00.0

Complete entry includes purpose, procedures, observations/results, and conclusions. Aspects of entries (title, purpose, etc.) are presented as percentages of possible entries (number of students x number of inquiries taught). Total inquiries taught = 8, 10, and 10 for Teachers A, B, and C, respectively.

statement. The consistency with which some or all aspects of inquiry were represented in notebook entries varied by class (see Table 2).

Noticeably absent in the notebooks were teacher comments on the quality or substance of the written work, and students' reflections on what they had learned. When present, teacher feedback consisted of checks and initials, or comments about the completeness of entries (e.g., "Where are your labels?" or "Where's the writing that goes with this?"). In classroom A, the notebooks contained one entry in which students reflected on their investigations of motors. For this purpose, the teacher provided three questions to guide students' self-evaluation: (a) "Can you wire the motors so they spin?" (b) "Can you explain, write and draw configurations?" and (c) "Can you work well in your group?"

In summary, the structure and content of notebooks varied between classrooms but not within classrooms because, as noted in the classroom observations, the teacher directed much of the students' writing. Entries followed

the inquiry structure for the most part, but the unit itself was not presented as an inquiry. Rather, investigations were presented and recorded as single independent events with relatively more attention paid to documenting results/observations than to generating conclusions. This lack of connection across activities combined with the low frequency of complete entries signals missed opportunities for fostering a genuine understanding of inquiry. In particular is the need to logically connect purpose, procedures, observations, and conclusions in the conduct of inquiry and to embed the findings of one investigation in the context of other investigations.

Types of notebook entries. In examining students' notebooks, we considered three types of entries: unit introduction/conclusion, inquiry investigations, and assessments. Each of these entries is expected to take on a different structure as fitting its purpose. The unit introduction/conclusion is viewed as a record of what students know at the beginning of the unit, a guide for subsequent investigations, and an opportunity to reflect on what has been learned at the end of the unit. The inquiry investigations are essentially a record of what was done and what was learned. The assessment entries are, in their simplest form, a check on students' understanding at various points in the unit. Below we describe the contents and structure for each of the three entry types.

Unit introduction/conclusion. The majority of notebooks in classes A and C had an introduction to the unit. None of the notebooks in class B contained an introduction to the unit. Rather, all those notebooks began with the first investigation activity, motors. All the unit introductions in classes A and C took the form of a group-generated chart. As such, there was little variation within a class. In class A students indicated in their notebooks "What we think we know" (i.e., things that use electricity) and "What we want to find out" (i.e., "Can electricity pass through glass?"). The cross-student consistency in the contents of these charts suggests that they resulted from class discussion and not individual students' reflections on what they knew about circuits. In class C, students worked in groups of four to complete a worksheet containing three columns with the headings—"we know" (e.g., "that some toys need batteries"), "we think we know" (e.g., "that electricity can jump from cloud to cloud then strike as lightning"), and "we want to know" (e.g., "how fast electricity travels"). Each group produced a different set of ideas and questions. Consistent with our classroom observations, an overall purpose

for the unit was not given and consequently not included in any of the student notebooks.

Inquiry investigations. Each of the 10 inquiry lessons or activities of the unit was recorded as an independent investigation in the notebook. A “complete” entry would include information relevant to each phase of inquiry—a purpose, a set of procedures, observations/results, and a concluding comment. We expected that student comments, questions, or reflections would be included as appropriate. Figure 1 is an example of a complete entry. The student lists a challenge (“Discover how electricity travels through a bulb and makes it light up”), lists the materials and strategy used, records observations, and then draws a conclusion about how electricity flows through the bulb.

A small percentage of the inquiry entries met our criteria of completeness (7.5%, 0%, and 25.9% for classes A, B, and C, respectively). More typically, a student’s notebook contained a purpose, procedures, and observations without any conclusions. Approximately 43% of the notebook entries included a purpose for an individual activity. Consistent with the classroom observations, these purposes were typically phrased in terms of a question (e.g., “What’s inside the bulb?”) or a challenge to do something (e.g., “Discover all of the ways you can use the materials to light the bulb.”). Rarely was the purpose expressed as an effort to develop some conceptual understanding (e.g., “What is the difference between a series circuit and a parallel circuit?”). Teacher B’s class did not record a purpose for any of its investigations. Our classroom observations indicate that indeed a purpose for the activity was given but students were not explicitly directed to write this purpose in their notebooks.

Observations/results were the most frequently recorded aspect of student inquiry (>85%) and the most consistent feature of notebooks across classrooms. Students recorded their observations in data charts (e.g., conductive and nonconductive material, the value of bulb brightness with changes in wire length and thickness) or free-form drawings (e.g., clockwise and counterclockwise spinning motors, series and parallel circuits with different numbers of batteries and bulbs). As noted, in the classroom observations, students followed a teacher-provided structure to record their findings. Drawings in classrooms A and B typically were complete and clearly labeled and on occasion accompanied by a statement of what was done (e.g., “I put the red wire on the positive side and the blue wire on the negative side.”). Students in class C were less consistent in this regard.

Challenge

Materials	Discover how electricity travels through a bulb and makes it light up.
1 copper wire	Strategy
1 bulb	
1 battery	

Draw a circuit & use arrows to show the path you think electricity follows. What part of the bulb lights? Study broken bulbs. What do you think are the critical contact points?

filament
glass bead
support wire
side terminal
base terminal
insulator

He and Kohlsh discovered how ~~the~~ electricity travels.

↓

the part lights.

Figure 1. Sample student notebook entry.

Conclusions, when present, were student-generated responses to teacher-generated questions such as “What is resistance? How would you describe it to a friend?” or “What is the difference between a series and a parallel circuit?” It was not uncommon to find the questions written in the notebooks but without a record of student responses or the class conversations we observed at the end of each investigation. In class A, notebooks were likely to contain summary statements or

definitions (as opposed to conclusions arrived at from an analysis of data collected during an investigation). For example, "a series circuit has one complete pathway only. It has more than one bulb. If one of the bulbs in a series circuit is unscrewed or burns out it opens the circuit and all the bulbs go out." Likewise in class B, student notebooks contained a list of relevant terms such as filament, conductor, and series circuit and their definitions.

The notebooks in class C stand out from the other classes in terms of the consistently high presence of purpose, procedures, and results/observations across the 10 inquiry lessons (>80%). Class C also had the highest percentage of complete entries, and for 3 of the 10 inquiry lessons, these entries consisted of some combination of teacher-dictated challenge and procedures and student-completed worksheets. The first page of the two-page worksheet provided a structure for students to organize their observations. The second page of the worksheet prompted students to draw conclusions from their investigation. For example, for the investigation of fuses, students were asked to connect a fuse in circuit with varying numbers of batteries and bulbs and observe what happens. Students recorded their data in a four-column chart in which they were to indicate the number of batteries in each circuit, the number of bulbs in each circuit, the type of circuit (series or parallel), and the results (i.e., what happened to the fuse). On the conclusion page of the worksheet, students were asked to draw two pictures of circuits to demonstrate their understanding of the role of a fuse in a circuit. Following this, they were asked to explain to a friend how a fuse works. The most complete response provided by a student was: "It works by breaking a circuit." Most of those students who responded to the prompt named the materials they used (e.g., "clay and steel wool"), provided a vague statement of the results (e.g., "sometimes it works, sometimes it doesn't"), or drew a task-specific conclusion (e.g., "the steel wool burns"). The teacher did not provide any written feedback to these responses, nor was there any indication that the teacher had read the students' responses.

In summary, the records of inquiry were largely incomplete. Students did record some of what was done for each investigation but typically without a conclusion or summary of what was found out or learned. Each inquiry was reported independent of the others (and without reference to the introduction to the unit). Further, teacher feedback on the form of the notebook entries (as opposed to the substance) and the consistency of notebook entries within classes (form and substance) suggests that the notebooks did not function as tools to assist thinking or

to assess what had been learned. Rather, notebooks served largely as logs of what was done. The high frequency of incomplete entries constrained the possibility that the notebooks—should students or teachers refer to them—could provide easily retrievable, useful information about what was done or learned. As currently formulated, the notebooks indicate little more than the frequency with which science lessons were conducted in the classroom and the topics of those lessons; evidence of thinking or learning is not sufficiently available to support using the notebooks for monitoring teaching or assessing student learning.

Assessments. There were two assessments included in the unit. The first assessment was given at approximately the midpoint of the unit. Students in class A drew the circuit configurations in their notebooks, predicted whether the bulb would light, and then checked their predictions against the results of their trials with the various circuits. Teacher A initialed each student's work but without comment on the substance of what was written. As we observed in class B, students worked in pairs to complete two worksheets (predictions, and explanation of consistency between predictions and tests). The teacher prompted students to refer to their notebooks to make their predictions as to which bulbs would light and which bulbs would not light. Records of students' work were not included in their notebooks. In class C, both assessments were completed by groups of students working together. The notebooks contained a generally incomplete embedded assessment.

For the end-of-unit assessment, a chart of data in the notebooks indicated the trials students carried out and the results (worked or didn't work) of each trial. Neither of the assessments received teacher written feedback on the substance or correctness of the students' responses. It is not clear whether teachers made use of this assessment information to inform subsequent lessons. Our observations suggest that the assessment was carried out as one more investigation, independent of the others and the overall purpose of the unit.

Comparison of Classroom Observations and Student Notebooks

In this study of notebook use in elementary science classrooms, we explored the integration of writing with the doing and learning of science. Our purpose was to ascertain the extent to which notebooks might serve as a tool for monitoring teaching and learning. We expected that the ways in which science is conducted in the classroom would have an impact on the structure and substance of students' notebook entries. Observations indicate that teachers presented the instructional

unit not as an inquiry about circuits but as a set of independent activities. Notebook recording was a consistent feature of these classroom learning activities. However, as noted, the instructional activities and the notebook writing were primarily teacher directed. Some aspects of writing were monitored consistently by the teachers (e.g., results/observations) and other aspects less so (e.g., conclusions). In this context, instructional goals for completing the activities and documenting what was done (i.e., product) overshadow the importance of the process of writing "not only for learning about something or acquiring knowledge, but for generating a personal response to something, for clarifying ideas, and for constructing knowledge" (Rivard, 1994, p. 970).

Comparisons of classroom observations to students' notebook entries indicate that some aspects of students' learning experiences are prominent in the notebooks (e.g., record of observations) and others receive little attention (e.g., record of problem-solving strategies). Classroom observations confirm that the notebooks reflect the number of opportunities students had to record observations, but do not capture the full range of opportunities students had to diagnose and solve problems. Rather, the notebooks tend to describe the final product of students' work, such as the switches that were most successful, or the observations about resistance that led to the expected conclusions. They do not reflect the problem-solving strategies, thinking, and reasoning students engaged in with their group or as a class. Nor do they reflect the complex discussions and decisions that led to entry contents. For example, the activity purpose is listed as a single question or challenge without any indication of the lengthy class discussion of concepts related to what students were about to do. Further, notebook entries do not illustrate the methodological problems students had to solve or the conversations they had as a class or as a group about the meaning of their data. Thus, notebooks seem to be an accurate reflection of those aspects of inquiry that teachers attend to; they give little indication of the quality of student thinking or understanding.

Discrepancies between what we observed in the classrooms and what students recorded in their notebooks speak to the inherent difficulties in translating the nature and purpose of inquiry (as described in reform documents) into classroom practice. Particularly challenging are juggling goals for task completion with goals for conceptual understanding. While we observed numerous instructional efforts to encourage students to think about previous experiences, their current findings, or the conclusions of others, these efforts were not reflected in the students' writing. As

such, our overall impression is one of missed opportunities. Nevertheless, many features of the observed instructional practice can be built upon to encourage and promote thinking and reasoning about science and a genuine appreciation for, and understanding of, inquiry.

Conclusions

Notebook writing in science is an important tool for recording observations, generalizing, hypothesizing, and theorizing—in other words, for assisting thinking, reasoning, and problem solving in the pursuit of science inquiry. The use of notebooks in science classrooms can encourage and make apparent the nature of student inquiry and knowledge development. However, the contents of science notebooks are sensitive to teacher influence, particularly in elementary science classrooms. As we observed, aspects of science instruction that teachers attended to (procedures, results) appeared in some detail in students' notebooks, but the use of data recording as a platform for thoughtful reflection, hypothesis generating, and the synthesis of ideas was generally absent. Teachers used notebooks to monitor what students were doing, and students, when prompted by their teacher, used the notebooks to remind them of what they had done. The mechanical use of notebook recording in these classrooms belies the essential role of writing in the conduct of scientific inquiry.

In the traditions of the scientific enterprise, accurate record keeping provides critical information on which to replicate studies and the substance from which formal presentations of findings and theories can be made. The validity of the resulting information is judged on the logical connection of evidence and assumptions with conclusions. Much of the debate about new or existing ideas takes place in the form of writing (American Association for the Advancement of Science, 1993). This ongoing documentation of the development of ideas and concepts provides an historical trace of the thinking and reasoning of working scientists and the factors that influenced their thoughts and conclusions at various points in time. It is this reflection and thoughtful discussion of results in context that make up the essence of scientific thinking. These processes of thinking must be made apparent to students if they are to develop an appreciation for the value and necessity of expressing ideas and interpretations in the conduct of science. Achieving this goal in the classroom shifts the focus from writing as a perfunctory part of doing science to writing as an essential feature of inquiry-based science learning.

As educators continue efforts to design and encourage appropriate experiences in the science classroom, consideration must now be given to how notebooks might be conceptualized, implemented, and assessed in a manner that most effectively integrates the doing of science with writing about it. One strategy is to create a guiding structure that can make visible the forms of inquiry relevant to various domains of science. Critical here is the relationship among investigations within a unit of study and the requirements for science process skills and science content knowledge in different contexts, as these have implications for learning and assessment goals (cf. Baxter & Glaser, 1998). In particular, differences in knowledge and process skills necessitate attention to variation in problem representation, legitimacy of procedures, nature of evidence, and the quality of explanations as appropriate targets for teaching, learning, and reflection.

A second strategy involves making explicit the relationship between writing form and function and opportunities for student thinking and reasoning. As is apparent, writing in and of itself does not guarantee learning (Gere, 1985). Rather, writing to learn requires that students and teachers take an active role in making the process apparent, purposeful, and relevant. In this regard, engaging teachers in a discussion of current uses of writing in science, students' use compared to scientists' use of notebooks, variations in writing expectations across grade levels, and teacher and student perceptions of the purposes for notebook writing merits attention. Important also is an exploration and review of a variety of learning situations where notebooks take on different formats (learning log, notebook, journal) and functions (affective, self-assessment, documentation). The results of these efforts provide the foundation for a series of professional development opportunities designed to call attention to various forms and functions of notebook writing and the implications of one over another in particular learning situations.

In tandem with these teacher-focused efforts, attention must now be directed toward establishing empirical verification of the impact of writing on student learning in science. Previous work suggests that learning logs, double entry journals, and quick writes are useful strategies for promoting some aspects of science understanding (Atwell, 1990; Butler, 1991; Jones, 1991; Willison, 1996). Are some strategies for notebook use more effective for promoting learning than others? What are the implications for learning, for example, of using notebooks for generating reports for public comment versus personal reflection across a set of investigations? These studies (and others) can provide useful descriptions of specific writing

techniques and activities that can be incorporated into science teaching in ways that foster subject-matter thinking and learning.

As an understanding of the role of writing in science learning develops, attention can turn to the appropriate use of notebooks for assessment purposes. Requirements for writing to support learning may differ substantially from the requirements for writing to assess learning. Important here are implications of this shift in focus (from learning to assessment) for structuring writing, describing essential features of writing that merit attention in scoring, and consideration of the nature and timing of feedback to students to support continued learning. For example, how might notebook use be structured to facilitate student self-assessment or instructional monitoring by the teacher? What types of supports are necessary in the classroom to facilitate attainment of these two goals in a cost-effective, instructionally informative manner? Answers to questions such as these provide an empirical basis for the appropriate design and effective use of writing to assess student science learning.

This study of the use of notebooks in elementary science classrooms makes apparent the inherent challenges in bringing the complexities involved in doing science into the classroom where pressures to complete units of study compete with goals for authentic science experiences. In the classrooms we observed, notebook recording was a consistent feature of students' science experiences. However, writing for the purpose of record keeping took precedence over communicating and debating findings. The challenge now is to build on existing practices in ways that effectively promote the traditions of science inquiry within the constraints of classroom practice. Notebooks or other forms of writing can facilitate teaching and learning in science classrooms if teachers harness the power of purposeful recording and thoughtful reflection about one's work (cf. Audet, Hickman, & Dobrynina, 1996). Writing of this sort links goals for learning with student understanding in ways that can position writing as a viable tool for monitoring teaching and learning in the science classroom.

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