

WRITING FOR SCIENCE
AND SCIENCE FOR WRITING:

THE SEATTLE ELEMENTARY EXPOSITORY
WRITING AND SCIENCE NOTEBOOKS
PROGRAM AS A MODEL FOR CLASSROOMS
AND DISTRICTS

Laura Stokes
Judy Hirabayashi
Katherine Ramage

With assistance from

Mark St. John
Kathleen Dickey
Allison Murray
Pamela Nagasawa

INVERNESS RESEARCH ASSOCIATES

August 2003

CONTENTS

EXECUTIVE SUMMARY	<i>i</i>
I. THE FOCUS AND PURPOSE OF THIS REPORT	Page 1
II. BACKGROUND	Page 2
Rationale for the study	Page 2
The Seattle Expository Writing and Science Notebooks Program	Page 3
Evaluations of the program	Page 4
Design and methods of the current study	Page 4
III. SUMMARY FINDINGS.....	Page 7
Contribution to student learning	Page 7
Enhancement of teacher practice and district programs	Page 7
Implementation at a significant scale	Page 7
IV. DETAILED FINDINGS.....	Page 8
A. Contributions to Student Learning	Page 9
Conceptual development.....	Page 9
Scientific skills and processes.....	Page 11
<i>Portrait: Learning science in 1st grade</i>	Page 13
Development of writing.....	Page 14
<i>Portrait: Learning to write in 3rd grade science</i>	Page 15
Students with a wide range of needs	Page 16
State standards and assessments	Page 18
Trade-offs related to teaching writing in science	Page 20
B. Current Level of Student Competence in Relation to Program Goals.....	Page 21
Ratings across grade levels and criteria.....	Page 21
C. The Quality and Value of the Professional Development.....	Page 24
Characteristics of SPS elementary science teachers	Page 24
Overall quality of the professional development.....	Page 25
The effect of the professional development on teachers' practice	Page 30
D. Implementation of District Science Program and Writing in Science	Page 32
Consistency of approach across classrooms	Page 32
Extent of implementation of district science units.....	Page 33
Extent of teaching writing in science	Page 34
Enhancement of curriculum in other areas.....	Page 37
Factors that influence teachers' use of writing in science	Page 39

V. REFLECTIONS ON THE EDUCATIONAL SIGNIFICANCE OF THE EXPOSITORY
WRITING AND SCIENCE NOTEBOOKS PROGRAMPage 41

 Contributions to educational improvementPage 41
 Further development and sustainabilityPage 42

REFERENCESPage 44

APPENDICES

- A. Design of the study
- B. Demographics of schools from which notebooks were sampled
- C. Notebook scoring criteria and scaled rubric
- D. Independent reviewer comment form
- E. Teacher survey

WRITING FOR SCIENCE AND SCIENCE FOR WRITING:

THE SEATTLE ELEMENTARY EXPOSITORY WRITING AND SCIENCE NOTEBOOKS PROGRAM AS A MODEL FOR CLASSROOMS AND DISTRICTS

EXECUTIVE SUMMARY

The Seattle School District's Expository Writing and Science Notebooks Program is an enhancement of the district's K-5 science program. Its aim is to improve the teaching and learning of both science and writing through a structured approach to having students write in their science notebooks as part of their science instruction. The program includes writing curriculum linked to each science unit and a series of professional development classes for teachers.

This evaluation report addresses the following questions:

- ◆ How and to what extent do the classroom approaches of the Expository Writing and Science Notebooks Program contribute to student learning in ways that are significant to the Seattle Public Schools and to the broader science education reform community?
- ◆ To what extent are elementary teachers in Seattle Public Schools implementing the district's science program *and* the writing component of the program?
- ◆ What are the benefits—to students, teachers, the district, and the field—of the Expository Writing and Science Notebooks Program when it is implemented to the degree that it is, as part of the district's elementary science program?
- ◆ What questions and opportunities remain for the program and for the district?

We asked independent experts to review the work in student notebooks to capture their perspectives on the key features, the quality, and the educational significance of student work in science notebooks. We also conducted a written survey of elementary teachers across the district to determine the extent to which science is taught, and to compare the teaching approaches of participants in the Expository Writing program to those of other teachers.

Findings

Outside reviewers who reflect multiple perspectives in education —classroom teachers, school administrators, science education faculty, leaders of policy and school reform initiatives—find that the Seattle student notebooks reflect approaches to the teaching

and learning of science and writing that the field believes are valuable but that are rarely observed in actual practice in schools and districts. The teachers participating in the program appear to be strongly committed to teaching science with writing, often in the face of competing pressures.

Contribution to Student Learning

The student notebooks show evidence of a systematic approach to teaching in which writing improves students' learning of science concepts and skills, and in which science serves as a potent context for the development of writing. Independent experts judge that the student work in science notebooks is, on the whole, more sophisticated in quality, and reflective of greater rigor and a higher level of learning of both science and writing, than is typical in science programs in other schools and districts that use similar science units.

Enhancement of Teacher Practice and District Programs

The curriculum strand, teaching practices, and professional development classes of the Seattle Expository Writing and Science Notebooks Program appear to be adding substantial value to teachers' repertoires of classroom practice in the teaching of science and writing in science. The Writing program thus enhances to a significant degree the district's elementary science program, and it helps bolster the district's literacy program, including the extent to which those programs help students meet state standards.

Implementation at a Significant Scale

Teachers across the district report that they teach a substantial amount of science—2.8 district units per year on average, of the 3 they receive. They do this even though they feel frustrated by the lack of time available to teach science as well as they would like. Participants in the Expository Writing and Science Notebooks Program spend more time teaching science, teach more writing in science, have higher expectations for students with special needs, and follow the district's science curriculum more consistently than teachers who have little or no experience with the Expository Writing program.

The Educational Significance of the Program

The Expository Writing and Science Notebooks Program is making a significant positive contribution to the Seattle Public Schools by enhancing the K-5 elementary science program at the level of classroom practice and at what appears to be a substantial scale across the district. The program is also serving the broader field by providing an example of an approach to teaching writing in science, and science in writing, that appears to be both feasible to implement and largely beneficial to teachers and students.

While there are some refinements the program should continue to make, these are minor. The major challenge it faces is how to become supported by, and integrated into, the district so that it can be sustained as a valuable and high quality program that serves teachers and students.

WRITING FOR SCIENCE AND SCIENCE FOR WRITING:

THE SEATTLE ELEMENTARY EXPOSITORY WRITING AND SCIENCE NOTEBOOKS PROGRAM AS A MODEL FOR CLASSROOMS AND DISTRICTS

I. THE FOCUS AND PURPOSE OF THIS REPORT

The Seattle School District's Expository Writing and Science Notebooks Program provides professional development workshops and curriculum components to teachers of science who are interested in teaching *writing* in science. The program is an enhancement of the district's K-5 science program. Its aim is to improve the teaching and learning of both science and writing through a structured approach to having students write in their science notebooks as part of their science instruction.

We at Inverness Research Associates have been studying the program for three years. This is the second report we have prepared (the first one can be found at <http://www.inverness-research.org/reports.html>). In this report we address four broad questions:

- ◆ How and to what extent do the classroom approaches of the Expository Writing and Science Notebooks Program contribute to student learning in ways that are significant to the Seattle Public Schools and to the broader science education reform community?
- ◆ To what extent are elementary teachers in Seattle Public Schools implementing the district's science program *and* the writing component of the program?
- ◆ What are the benefits—to students, teachers, the district, and the field—of the Expository Writing and Science Notebooks Program when it is implemented to the degree that it is, as part of the district's elementary science program?
- ◆ What questions and opportunities remain for the program and for the district?

At the outset, we wish to state that the evidence in this report—gathered from teachers and administrators within the SPS, as well as many experts and reform leaders independent of the district—builds a case for the Expository Writing and Science Notebooks Program as an exceptional investment in the improvement of science teaching and learning. We believe this program serves as a model of teaching writing in science and teaching science with writing that is of real significance to the students and teachers of Seattle, to the Seattle Public Schools, and the broader science education and reform community.

II. BACKGROUND

Rationale for the study

The idea that writing, as a mode of language use, can contribute to the learning of science is not a new one. In fact, considerable research has been done within this problem area in the last two decades, much done by applied cognitive scientists.¹ The National Research Council, author of the National Science Standards, advocates writing for students to learn science and for teachers to assess learning.² In our evaluation studies of NSF-funded Local System Change projects over the past five years, we have observed that science notebooks are widely considered to be an important component of a hands-on, investigation-based science program;³ however, we have seen no other concerted effort of the kind that has been made in Seattle to support teachers' consistent and purposeful use of notebooks.

Existing research is not conclusive about whether there is a "right way" to include the teaching of writing in science.⁴ A number of studies suggest, though, that teaching students specific language structures or writing frames associated with scientific reasoning (e.g., drawing inferences from data) or associated with scientific genres (e.g., explaining concepts or reporting lab results) can help students generate more precise conceptual understanding and produce clearer writing. Many, but not all, of these studies have focused on high school or college students.⁵ Additionally, there has been some research on promoting science learning for bilingual students through structured writing.⁶ The approach to writing in science that the Expository Writing and Science Notebooks Project takes is situated within this general school of thought.⁷ The particular strategies of the program (the specific writing frames and their use, the focus questions and their relationship to the foundational science units), however, are unique to this program to the best of our knowledge.

The Expository Writing and Science Notebooks Program has two key features that are of interest for research and evaluation purposes. First, the program is based on a hypothesis that is potentially very important to the Seattle schools and also to education

¹ See Holliday, et al. (1994), Rivard (1994), and Yore, et al. (2003)

² See NRC (1996)

³ For example, in Las Vegas, El Centro, Gilbert, and Pasadena.

⁴ There are not only competing theories about how writing and science literacy may support one another, but there are also competing goals for student learning with respect to science and writing, and different theories of best contexts for student learning. It would be remarkable if there were, in fact, agreement in research or practice about a "right way."

⁵ See Greenbowe (2002), Hand (1995), Kelly and Takao (2002), Keys (1994), Keys (1999), Keys, et al., (1999), Keys (2000), Kirkpatrick and Pittendrigh (1984), Klein (1999), Klein (2000), Klein (2002), Rivard (1994), Wallace (formerly Keys) (2002), and Warwick, et al. (2003).

⁶ See Merino and Hammond (2002)

⁷ There are other studies suggesting that writing genres generally characterized as "creative," "reflective," or primarily based in students' language help students learn science (Bass, et al., 2002; Hildebrand, 1998; Shepardson and Britsch, 2001). Seattle's program does not ascribe to this general approach.

more broadly—that is, that instruction in writing can help students develop scientific understanding, and that writing about science can help students develop more generally as writers. Second, the Expository Writing and Science Notebooks Program is designed in such a way that it has real potential for classroom implementation: it has an explicit and structured approach to teaching writing in science, with a curriculum for writing that is embedded in the science curriculum, and it has a professional development component linked tightly to the curriculum and teaching strategies. When used in concert with a foundational science curriculum, the program has strong potential for large-scale (district-wide) implementation, and thus strong potential to support improvement of teaching and learning. In fact, the project is essentially a “natural experiment” that is being carried out at the scale of a large urban district. Both of these features are central to the guiding questions of this study.

The Seattle Expository Writing and Science Notebooks Program

The Expository Writing and Science Notebooks Program began in 1999-00, offering 90-minute workshops to teachers as part of the district’s NSF-funded Local Systemic Change project. According to program records, nearly 900 teachers (or more than 80% of the K-5 teachers currently teaching in the district) have participated in at least one workshop since the program began.

The program has three components:

- Supplemental curriculum for expository writing specific to each of the 18 hands-on units used in grades K-5. These include focus questions for writing, as well as thinking/writing frames and graphic organizers designed for the specific lessons in each unit. This curriculum strand was introduced into the program in 2001-02.
- Professional development that is available to large numbers of teachers across the district. There are two components. The first is an introductory three-hour program (two 90-minute workshops each), one for primary grades and one for intermediate grades. The second component is a set of three 90-minute workshops for each grade level, one for each of the units taught at that grade. These 18 grade-level workshops are updated each year.
- Teacher leadership development for three to five teachers per grade level. Lead Science Writing Teachers (LSWTs) assist in developing and field-testing curriculum strands and materials for workshops. LSWTs meet monthly; thus, they have substantially greater professional development opportunity and continuity than other participants in the program. Following our evaluation study in 2002 (described below), LSWTs added the reading and discussion of whole student notebooks (not just excerpts) to their meetings in 2002-03.

Evaluations of the program

Previous studies (2001, 2002)

We at Inverness Research Associates have studied the program for three years. During the first year (2000-01) we familiarized ourselves with the program by observing professional development workshops and interviewing key staff members; we also conducted in-depth interviews with a sample of twelve teachers identified as having varying degrees of participation in the program. In the second year (2002), we focused our study on assessment of a sample of 150 notebooks of students whose teachers are participants in the program. For this study, we created a scaled scoring rubric, in cooperation with program staff. Twelve Lead Science Writing Teachers read and scored the notebooks. We also invited a small number of independent experts to review the notebooks and offer us their assessment of the quality of student work, and by inference, the potential of the program to support student learning in ways that are valued in the broader science education community. Data from those scoring sessions, along with the teacher interviews from the year before, were used in our August 2002 report. (The report is available on the Inverness Research website at: <http://www.inverness-research.org/reports.html>.)

The results and evaluation tools generated from the 2002 study made an important contribution to the current-year (2003) study. That study produced evidence that student notebooks of participating teachers do in fact reflect the standards of the program, and also reflect a substantial degree of student progress toward development of the skills and knowledge valued in the program. Based on this study and on the major components of the program's design, we hypothesized that this program is probably amenable to large-scale implementation in the district. We also hypothesized that the contributions that this program appears to make to student learning are of significance and value to the broader field.

This study

The study we carried out this year took up these hypotheses, and thus it had two distinct but related foci. One focus was on the value and significance of the program's approach, from the perspective of independent experts in science education and reform; the other focus was on the degree of implementation in the district.

Design and methods of this study⁸

Our guiding questions were these:

⁸ We describe our approach briefly here. In Appendix A, we spell out more detail associated with creation of the sample of notebooks, the design of the notebook reading/scoring sessions, and the process of sampling for the teacher survey.

1. To what extent is there evidence suggesting that the project is contributing to students in terms of their skill in expository writing, their understanding of important science concepts, and their ability to think scientifically and carry out scientific inquiry?
2. To what extent is this project pursuing an approach that is feasible for all elementary school teachers within the district?
 - a. What approaches to teaching science, and writing within science, are currently in use across the district?
 - b. To what extent is the project influencing the teaching of science, and of writing within science, throughout the district?

To address these we carried out a study with two distinct components. For question 1., we conducted an independent review of student notebooks; for question 2., we conducted a district-wide teacher survey. We describe the design of each below:

1. **Independent review of student notebooks.** Our purpose for the notebook study was to gather the perspectives of **outside reviewers** on the key features, the quality, and the educational significance of student work in science notebooks produced in classrooms where the program is quite fully implemented. For this study, we drew a sample of 60 student notebooks, 20 from each of grades 1, 3, and 5 reflecting a diversity of Seattle schools⁹. We devised two approaches to having these notebooks reviewed.
 - a. Independent teacher scoring and teacher reviews of student work. We invited 15 teachers of grades K-5 who are not participants in the science writing program to assess the student work in the notebooks. Six of the teachers teach in Seattle, six are National Board certified teachers in Washington, and three are Puget Sound Writing Project fellows. The teachers are all experienced at teaching science and/or writing at the grade level they were reading, and several of them have had some experience teaching some of the same science units. They scored the notebooks on three criteria, using the scaled rubric that we created and piloted in the 2002 study¹⁰.

Additionally, we conducted focus groups with these teachers at each grade level. We asked the teachers to give us their candid assessments and impressions of the work they saw in the notebooks, from their perspectives as classroom teachers. Here, our purpose was to ascertain their independent views as educational experts. In the findings sections, we include these teachers' comments alongside the comments of the other independent reviewers.
 - b. Independent reviews of student notebooks by experts from within the Seattle district administration and outside the district. We invited 10 mid-level administrators from the Seattle Public Schools,¹¹ one SPS school board member, and 16 independent experts from

⁹ See Appendix B for demographic characteristics of schools.

¹⁰ See Appendix C.

¹¹ The superintendent, chief academic officer, and head of professional development and curriculum were all scheduled to participate but none were able to do so when the time came.

other schools, universities, reform projects in other districts (and one other state), and reform projects that are regional and state-wide. These readers were selected as proxies for “the field,” i.e., as representatives of the larger science education (and writing education) community who, together, embody the standards and best practices related to teaching science and writing in science. Our purpose was twofold. Primarily, we wanted to gain an independent and expert perspective on the nature and qualities of the work in the student notebooks and, by extension, of the educational significance of this project *vis a vis* the standards of the science (and writing) education reform community. Secondly, we wanted to engage SPS administrators personally in examining the student work and reflecting on the significance of the program to the district *vis a vis* its own reform agenda.

We involved these reviewers in three activities over a full day:

- *Collective reading and whole group discussion of three selected notebooks*, one from each grade level.
- *Independent reading and written comments on three full notebooks* by each reviewer. (A copy is in Appendix D.)
- *Focus groups of SPS affiliates and non-SPS reviewers*. We asked the reviewers to tell us their overall impressions of the notebooks, after having read and analyzed several in detail, and we asked them to reflect on the educational significance of the notebooks as artifacts related to teaching and learning.

2. **Survey of elementary science teachers across the district.** Our purpose for the survey was twofold. First, we wanted to capture the extent of implementation in the district of hands-on science teaching and the teaching of writing in science. Second, we wanted to compare the practices of participants in the Expository Writing and Science Notebooks Program with those of non/limited-participants. We sent surveys to 576 teachers total in grades K-5. The overall response rate was 53%, which is quite robust. Participants had a higher response rate of 61% *vs.* 48% for non/limited-participants.

Creating the two sample groups (participants and non/limited-participants) was not a straightforward task. The Expository Writing and Science Notebooks Program has been in existence since 1999-00. From program records, we can infer that the great majority of the ~950 elementary teachers currently teaching in the district have participated in at least one workshop. In order to create a large enough overall sample to measure district-wide implementation, and at the same time, divide that into the two comparative samples, we ultimately used these designations and definitions: “participants” are teachers who have participated in 2 or more workshops within the past three years (2000-01, 2001-02, and 2002-03); and “non/limited-participants” are any teachers randomly selected from all elementary schools who did not fit the definition of participant. This method produced samples of 278 teachers in each group, for a total of 576. Within each group, the same number of teachers per grade level were sampled.

Defining the samples in this way had the potential to reduce the contrast between the two groups, because two (or more) workshops in three years cannot be deemed “heavy” professional development; also, we knew that the sample of “non/limited-participants” included some teachers who had participated in one workshop offered by the program within

the past three years and perhaps a few who had taken two in four years. Given this, we believe it is especially impressive that there are many significant differences between the two groups with respect to the teaching of science and the teaching of writing in science.

III. SUMMARY FINDINGS

The combined results of our two-part study develop a portrait of a program that is clearly enhancing the district's science program and producing important positive outcomes at the level of the classroom and at the scale of the district. In fact, we believe it is remarkable indeed that the perspectives of program participants, district staff, and outside independent experts are so congruent with respect to the value and contributions of a program.

Summary findings:

Contribution to Student Learning

- ◆ The student notebooks produced by Lead Science Writing Teachers show evidence of a systematic and consistent approach to teaching in which writing improves students' learning of science concepts and skills, and in which science serves as a potent context for developing writing.
- ◆ Independent experts judge that the student work in science notebooks is, on the whole, more sophisticated in quality, and reflective of greater rigor and a higher level of learning of both science and writing, than is typical in science programs in other schools and districts that use similar science units.

Enhancement of Teacher Practice and District Programs

- ◆ The curriculum strand, teaching practices, and professional development classes of the Seattle Expository Writing and Science Notebooks Program appear to be adding substantial value to teachers' repertoires of classroom practice in the teaching of science and writing in science. The program thus enhances to a significant degree the district's elementary science program, and helps bolster its literacy program, including the extent to which those programs help students meet state standards.

Implementation at a Significant Scale

- ◆ Both participants and non/limited-participants in the Expository Writing and Science Notebooks Program report that they teach a substantial amount of science—2.8 district units per year on average, of the 3 they receive. They do this even though they feel frustrated by the lack of time available to teach science as well as they would like.

- ◆ Participants in the Expository Writing and Science Notebooks Program spend more time teaching science, teach more writing in science, make more use of the specific strategies of the Expository Writing and Science Notebooks Program, have higher expectations for students with special needs, and follow the district's science curriculum more consistently than non/limited-participants.
- ◆ The Lead Science Writing Teachers whose notebooks were used for this study have more access to ongoing professional development for writing in science than regular participants in the Expository Writing and Science Notebooks classes. Nonetheless, the high degree of program implementation by regular participants suggests that a substantial proportion of Seattle students are experiencing at least some of the learning benefits of the program's approach to the use of science notebooks.

IV. DETAILED FINDINGS

In this section we report a number of findings within four areas:

- A. The ways in which the curriculum strand and teaching strategies of the Expository Writing and Science Notebooks Program contribute to student learning;
- B. The levels of competence in science and writing attained by students whose teachers are Lead Science Writing Teachers in the program, measured against the goals of the program;
- C. The quality of the professional development offered in the program and its influence on teachers' classroom practices;
- D. The extent to which the district's science curriculum, and the approaches of the writing program, are being implemented across the district, and the factors that influence teachers' teaching of science and writing in science.

We synthesize evidence gathered from all sources:

- independent reviewers' assessments of the work in the sample of student notebooks,
- the formal scoring of the notebooks by teachers who are not participants in the program,
- the survey ratings of teachers who are participants and non/limited-participants in the program, and
- comments on the survey by teacher respondents.

A. Contributions to Student Learning

In this section we examine what types of learning appear to be supported by the Expository Writing and Science Notebooks Program, and the ways in which science and writing seem to interact to foster learning. These findings are based on independent reviewers' assessments of the work in student notebooks, as well as results of the teacher survey.

Conceptual development

- ◆ **The curriculum strand and teaching practices of the Expository Writing and Science Notebooks Program support students' conceptual development and understanding in science, and support cumulative development of concepts over time.**

Independent notebook reviewers saw considerable evidence that the writing approaches enhanced students' understanding of the concepts included in the science units:

They [the students] took everything, they took the good frameworks for the writing, they took the knowledge that they had, the scientific concepts, and then they added their own understanding.

There is also a lot of opportunity in the context of those notebooks for analysis and synthesis and so, through the writing that requires you to do that, you are having to really think deeply about the science, and dig a little deeper into the concepts than you might otherwise do.

Reviewers could also observe cumulative development of conceptual understanding occurring over time, as the progression of writing experiences followed the scientific investigations in the unit:

It seemed like in a number of them, if they didn't get something at first, or they are a little confused or the notebook was empty at first, it seemed like by March they were getting it, understanding more.

In written comments on the teacher survey, some respondents also noted that students develop skills over time through consistent use of notebooks:

In 1st grade, the quality/skill level is dramatically different at the beginning than the end of the year...it's a little hard to get quality science writing at the beginning of the year, but if students do participate in science writing routinely, their overall writing skills improve much more dramatically than if they hadn't done science writing at all!!

Results of the teacher survey show that teachers who are participating in the writing program are more likely than non/limited-participants to report that writing in science contributes substantially to student learning of science. The graph on the following page shows that 73% of participating teachers believe writing contributes "a great deal" to science learning, compared to 54% of non/limited-participants. In their written comments on the survey, participants put this benefit in their own words:

I think it helps students construct their own meanings from their own experiments and data. It proves/disproves what they truly understand about science concepts. A child can observe and conduct an experiment and still not really understand the results.

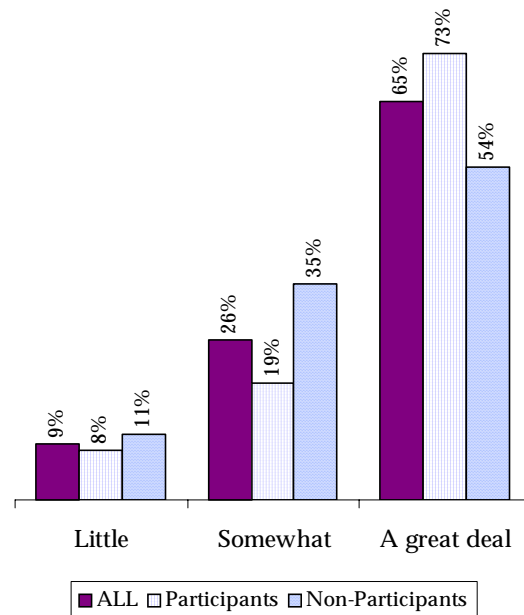
Adds to student's understanding, clarification, and enjoyment of science.

Allowing kids time to mentally process a science concept.

It causes students to reflect on the new information or continue to organize what they've learned.

Figure 1.

CONTRIBUTION OF WRITING TO STUDENT LEARNING IN SCIENCE
(PERCENTAGE OF TEACHERS REPORTING)



For purposes of brevity, we use the term “non-participant” in the legend for each graph in this report. As explained above and in the methods section, this group is more accurately described as “non/limited participants” because some have experienced a workshop.

There was one exception to the generally high level of enthusiasm for the potential of this approach to support conceptual development, and it was expressed by all sets of reviewers. They suggest it is important to use some more open-ended writing prompts to extend the conceptual possibilities of district science units that are less rigorous and rich. From a teacher, referring to the 3rd grade unit on plant growth:

There also were some questions that to me seemed to beg for further investigation. Like what would happen if we planted the brassica plants outside . . . I didn't see a place in any of the notebooks where that was allowed for follow-up, that component wasn't present.

This is less a criticism of the writing program than of some of the units, but it does ask the writing program to do more than simply serve the units; rather, it expects the writing component sometimes to take the lead in enhancing students' science experience.

Scientific skills and processes

- ◆ **The curriculum strand and teaching practices of the Expository Writing and Science Notebooks Program enable students to learn skills and processes of scientific investigation, and to do so with engagement and a learning purpose. Reviewers note that the approach would support even greater learning and be more authentically scientific if it included more opportunities for student-generated writing.**

One of the great challenges of "hands-on" science teaching is to facilitate students' interactions with materials in such a way that students actually develop both their scientific skills and conceptual understanding. Put another way, the challenge is to avoid the problem of engaging students in "activity-for-activity's-sake." The Expository Writing program's approaches to teaching writing in conjunction with the district's science units seem to help teachers engage students in purposeful exploration and investigations, using the skills and processes of inquiry.

Independent reviewers noted considerable evidence in the notebooks of students' purposeful use of the skills of scientific study and development of scientific thinking. A teacher-reviewer noted this:

Questioning and making predictions are high level and they [students] have opportunity to do that.

Reviewers noted that the writing approach compels students to actually examine and make meaning of the data they have collected from an experiment. One reviewer, a high school teacher of science, observed this in a 5th grade notebook, and notes that it is an often neglected skill:

There was an opportunity for them to table information and then they actually sat down and discussed that table in a piece of writing text, and so they have that reinforcement of the learning. They really clearly followed all of the different elements that had been laid out in the table. Working with the high school students, often times they would collect the data and put it in a tabular form, but then they would neglect to actually have a discussion about it, so to see 5th graders doing that is really encouraging. You don't make the table just to tack on the wall somewhere, but it is a place for you to begin your review of the evidence, to link it all together and be coherent.

On the teacher survey, participants in the writing program wrote a number of comments describing ways in which the approach helps students learn to investigate, think, and write as scientists. A sample:

- Students learn how to be scientists, thinking critically about their discoveries.

- Shows how important it is to develop your scientific findings. Allows children to write answers to their experiments, to compare and contrast, and to go from a good guess to the exact.
- Students make connections from experiments to concepts.
- Students learn how to express their ideas scientifically and how to explain procedures and what they see.

In their comments on the survey, several teachers also noted that the writing approaches seem to engage students more deeply and enthusiastically in their scientific work:

- Engages kids more deeply and meaningfully in the science activities/ skills/ and learning.
- My students love their notebooks. They take great pride in their writing. They show so much growth!
- Students think of themselves as real scientists! Just like scientists, they are observing, recording, and analyzing. They think this is pretty neat!

Independent reviewers also noted a degree of student engagement in science that is rarely seen. One commented, when reading a 3rd grade notebook where students recorded the growth of a plant, that:

The student is obviously engaged on a personal level. He is writing about *his* bean and *his* plant!

Among the independent reviewers, there was also a minor concern that the notebooks sometimes demonstrated too much guidance by the teachers and too little student-directed work. One reviewer, formerly a scientist, noted that authentic writing in science notebooks involves discipline and structure, but also spontaneity:

I used to be a scientist, and when I was a scientist, I kept my notebook when I did research and I usually wrote in it when I felt like it. I had notes in it and it seems like there is not that aspect to the kids taking ownership of their own notebook. It could be a little more spontaneous. I don't think some of these kids see the grander purpose in keeping the notebook.

All sets of independent reviewers suggest that the writing program offer more open-ended writing prompts to foster student-generated writing and original/independent reflection on the concepts they are learning. The focus questions and frames create an effective starting point for students but they may ultimately create a "ceiling" effect when used in a rote fashion; students need explicit opportunities to move beyond the frames. One reader offered a suggestion:

Where is the place for the revelations that come? Maybe they can put another section in the notebooks for student revelations, something that is more spontaneous, student generated.

The advantage of using a frame is often the kids have the idea in their head but they are not sure how to structure what they want to say and the frame can help with that. But when you adhere too strictly to the frame, then you get a whole lot of the same thing over and over again. I didn't notice that the kids ever had an opportunity to say, 'okay, I have learned that frame, now do I do that on my own when I am doing my own thinking about my own writing?'

Portrait: Learning science in first grade

The following sample of entries from a 1st grader's notebook on the "Balls and Ramps" unit shows science learning in action, including the purposeful use of scientific skills (observation, testing, recording of data, using data to explain); development of conceptual understanding from investigation (properties of balls and ramps that affect speed of roll); and development of scientific habits of thought (prediction, question formation) and scientific discipline (fair test). The science unit itself establishes and sequences the concepts and the investigations to develop them; the writing program provides the prompts and assignments that elicit the writing about the scientific work.

Students begin the unit by studying the properties of balls by describing what they are made of and their shape (in words and drawings), by weighing them, and by testing their bounciness and how they roll. In the following, a student draws from data recorded on a table in his notebook to support a statement about which of two balls is heavier:

The rubber ball weighs more than the polystyrene ball because the rubber ball weighs 10 and the polystyrene ball weighs 3.

After an investigation of balls' behaviors in specific conditions—again with data carefully recorded on charts—this student concludes that heavier balls are harder to roll on flat surfaces:

The marble was harder to move because the marble weighs 8 cubes and it's glass, heavier.

The students then test the behavior of balls as they roll down ramps. To do this, they predict whether the size or weight of the ball, or the height of the ramp, will affect the speed and distance the balls roll. This student, for example, predicts that size will affect the speed of the roll down a ramp:

I predict that the marble will win because it is little.

The students then conduct a series of tests of what variables affect the speed and distance of roll down a ramp; they again record data in a series of dated entries. Students then examine their results and explain whether their prediction was correct and, if not, what happened instead. In the following, the student notes (correctly) that the height of the ramp, not the weight or size of a ball, affects the speed and distance of the roll:

The weight and sizes doesn't matter but something does matter how high it is.

To arrive at this conclusion, the student has had to conduct the investigation carefully to isolate variables and produce unbiased results. In this case, for example, the students have built two test ramps, one that is "one block" high and one that is "two blocks" high, and have rolled different-sized and weighted balls down each. In the following, the student explains why this was a fair test:

It was a fair test because everyone started at one block and ended with second block.

The student then raises a new question that his result provokes:

I wonder what would happen if I had more blocks to make it higher?

[This notebook received scores of "4" on each of the three criteria. See section B for an explanation of the scores.]

Development of writing

- ◆ **Expository writing is an important area for students' development of literacy. Hands-on, investigation-based science is an effective context for the teaching and learning of expository writing. Writing fosters thinking about and internalization of concepts through language; science experience generates important, compelling content about which to write.**

Independent reviewers noted the importance of explanatory and analytic writing as a part of students' repertoires, beyond the narrative forms more typically taught in elementary grades. A reviewer of 5th grade notebooks said this:

I think from age 0 to 10 they are into narrative type stuff, but as kids get older from 10 to 20, you are moving so much more into expository type, persuasive type, of writing and writing letters. Think of your university—they ask the kids, 'can you explain to us why you think you should attend the UW?' Not that I would ever want to say to a 5th grader, 'you are going to have to use this when you apply to college,' but if you don't start it there, they don't have the foundation. The majority of what you do as an adult is that type of writing. I don't know the last time I wrote a story.

Reviewers found considerable evidence in the notebooks that students are being taught a number of specific writing strategies in a systematic way:

It was clear that the kids had been coached in using transitions to try to structure their statements logically, and that was reflected in how they wrote.

The teachers have clearly prepped the kids with organization

Independent reviewers noted that hands-on, investigation-based science is a very effective context for the teaching of expository writing. The writing approach enables students to focus on the science concepts more intensively, develop scientific concepts more fully, internalize them in their own words and with the use of scientific vocabulary, and communicate those concepts effectively. Teacher reviewers noted especially that writing compels students to make conceptual sense for themselves. Comments from reviewers:

[Writing] makes them have to stop and think about it. If we are having a conversation and I am trying to teach you something, when you have to sit down and actually write it out, you are having that time for thinking and sticking it somewhere, instead of just of tuning out.

It makes observation and reflection much more important as they are doing these experiments. I have taught this unit, and it is possible to do this unit without very much thought. So the observation and reflection required is really useful.

It is rather rare that science is the basis for our writing. Multiple writing is based in some literary experience that you just had, or some life experience we are fishing for, and very little of what the children are asked to write is based in some specific, observable event that we all shared...[new speaker] And piggybacking on that, kids don't do a lot of expository writing because they don't have a reason to do expository writing. This gives them the reason to do it.

On the teacher survey, participants and non/limited-participants alike identified the benefits of teaching writing in the context of science. Again, they see a powerful reciprocal relationship between writing to learn science and science as a context for learning to write:

- As I work with very young students; science is such a natural way to teach expository writing.
- Fosters reflection and thinking. For young children it is easier for them to write about what they are experiencing and what they see. Science writing meets children at this appropriate developmental stage.
- Helping students communicate their knowledge and understanding of science. Helping students with expository writing and make the connection between science, writing, and reading.
- It is a way to meaningfully use expository writing in the classroom which is often difficult to incorporate.
- Students generally not motivated to write are motivated in science.

Just as reviewers had noted the cumulative development of conceptual understanding in the notebooks, they also saw students' cumulative development as writers. A number of them noted that teachers and students alike gain appreciation for student learning when they reflect on this development. One reviewer of 5th grade notebooks:

I felt that I watched the inquiry writers improve in their writing as the unit went on... I don't think we look at a whole body of work over time enough as teachers. And I would be interested to know what students' reaction would be to look at all that they did. When we do papers and papers, they don't realize the whole compilation of it, as they would in a notebook.

Portrait: Learning to write in 3rd grade science

Independent reviewers noted that notebooks in all three grades showed evidence of a structured and purposeful approach to teaching organization and development in scientific writing. In 3rd grade, the science unit is about plants and plant growth. Very early in the unit, students are asked to observe carefully and describe the bean they will plant, both in a dry state and a wet state. One observer noted that students used their notebooks to record observations, then organize their details analytically (in this case, to compare and contrast), and draw from those notes to write:

One had a little graphic organizer and they had a box where they put the key words about the differences between the 2 beans and then used those to write the paragraph.

Below are entries from two student notebooks showing the resulting paragraphs, which describe the differences between the wet and dry bean. The first notebook was given an overall ratings of "3" (adequate) on the writing criterion.¹²

I observed lot's of different things about my wet bean. For example it was softer and it was sticky. Also it was bigger and had a strong smell of odor. Then I looked at it and it was cleaner but tanner

¹² See Section D below for information related to the scoring criteria and findings related to the level of competence exhibited in the sample of 60 notebooks.

than before. It was also 3 centimeters long. The spot on it was totally gone. Finally it was a bit heavier than last time. This is exactly what I seemed to observe about my dry bean.

The notebook below received an overall level of “2” (developing) for the writing criterion. The reviewer noted, however, that this entry showed evidence of engagement and student voice, very positive traits in writing.

There are changes since I observed the dry bean. It is now wet. It smells like frosting. I also noticed that it is longer and softer. There's also no cracked shell. In fact there's no shell. It even feels softer. It also looks bigger. Even the lines dissolved. And boy, does it look cleaner. I don't hear anything though.

Students with a wide range of needs

- ◆ **The curriculum strand and teaching practices of the Expository Writing and Science Notebooks Program provide powerful learning experiences and opportunities for success to a very wide range of students. When implemented with care and sensitivity, the approaches are especially helpful in creating a scaffold for English Language Learners, Special Education students, emergent writers, and other students with special needs. Teachers participating in the program are more likely than non/limited-participants to deem it advantageous for struggling students. When implemented in a non-rote fashion, the approaches also help high-performing students communicate well in writing.**

All sets of independent reviewers saw evidence in the student notebooks that the program's approach to writing in science can serve the needs of the full range of students. One outside teacher put it this way:

I have a lot of very highly gifted kids from 130 to 140 IQ that don't have an ability to organize all that they can conceptualize. They would resist this ... but for them to be able to communicate what they know at a high level to what anybody else is going to understand, they have to have some sense of organization, some kind of common language, as opposed to some random nightmare which I have seen many times. And so this becomes a teaching tool to those kids not to learn science, but to learn to communicate. At the other end, it may be for some kids how to learn science. I see it has multiple purposes.

Reviewers noted especially that the structured writing prompts seem to be helpful in scaffolding the development of English Language Learners, Special Education students, and any others who struggle to write and struggle with concept formation. Some observe, for example, that the writing strategies enable both English Language Learners and native speakers to develop vocabulary in a systematic way and also improve their command of standard English. In some notebooks the work of designated ESL students is indistinguishable from that of native speakers. Reviewers also saw evidence that, for students who struggle with writing, this approach offers them multiple and repeated occasions to write and to produce a volume of writing, as well as good starting points for writing, thus developing their confidence. They note further that writing in the context of science offers students of all backgrounds the same set of rich, first-hand experiences from which to write, thus “leveling the playing field.”

A district administrator noted that this approach enables ELL students who are from non-western cultures and linguistic/logic systems to learn about and internalize the western scientific process approach. Teacher reviewers noted that this approach also involves drawing, graphing, charting, and diagramming along with writing so that students struggling with writing can participate and learn:

That is what I like about all of the drawings. My lowest functioning kids—those below grade level and my ESL kids—could look at the plant, draw it, measure it, even if they can't really write all about it.

A district administrator noted further that the writing program offers the type of scaffolding that can enable Special Education students to participate, learn and produce quality work in mainstream classes. A teacher reviewer noted that the structured approach gives the youngest writers a way to get started:

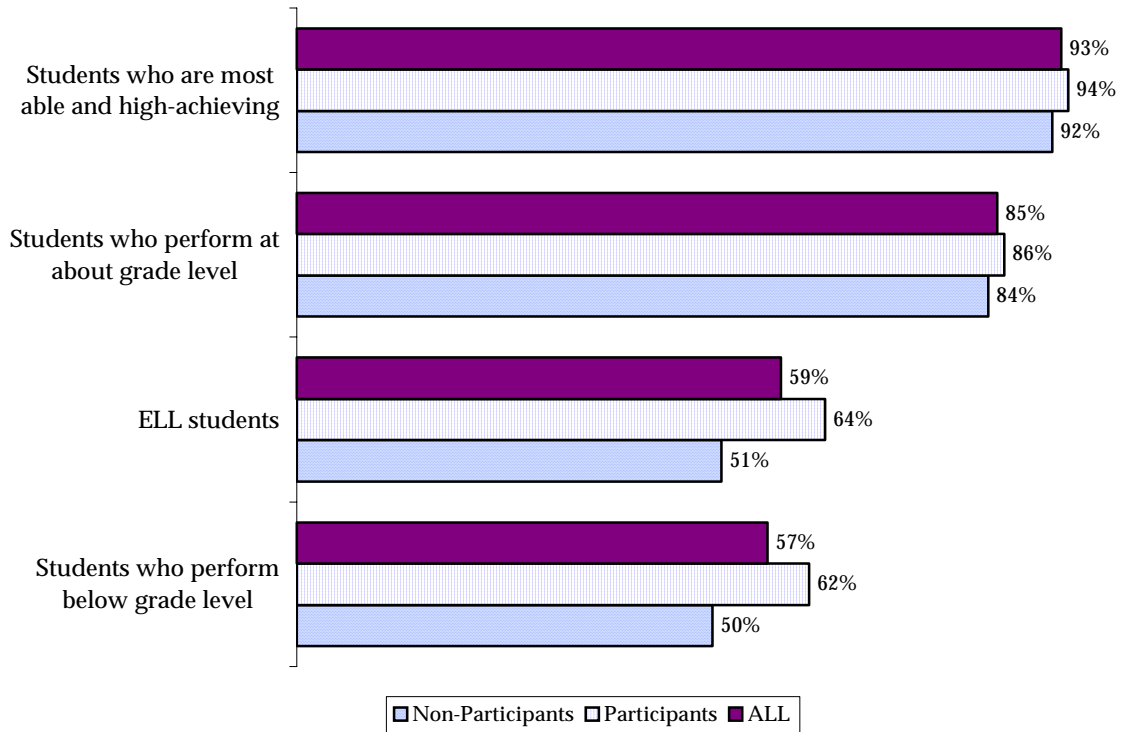
I think the advantage of using a frame is that often the [1st graders] just don't know how to start what it is that they want to say. They have the idea in their head but they are not sure how to structure, and the frame can help with that.

There were two relatively minor caveats to these observations. First, for ESL students, occasionally the written language barrier is severe enough to block students' progress in writing and in the development of science; for these students, extra time and support are necessary. Second, for all students, but perhaps especially those working at or above grade level, the writing strand may at times have a "ceiling" effect by offering too little encouragement for student-directed writing and investigation.

Results of the Seattle teacher survey show that teachers who participate in the Expository Writing program have somewhat different views than non/limited-participants about the value of writing in science for the full range of students they have. The great majority of participating teachers and non/limited-participants alike report that writing is helpful for students who are at or above grade level. However, participants are more likely than non/limited-participants to report that writing is helpful to ELL students and students who are working below grade level. The graph on the following page shows that, among participants, 64% believe writing helps ELL students, compared to 51% of non/limited-participants. Also, 62% of participants believe writing is helpful to low-performing students, compared to 50% of non/limited-participants. Similarly, participants' written comments on the survey reveal their views:

- Because of the structure and frames, science writing is within reach of low achieving students; it gives them confidence to write in other areas.
- My students are becoming better readers. I teach 1st grade in a school where 1/2 of my students are bilingual. They are learning science vocabulary and other sight words in context.
- Opens the world of writing for reluctant writers, those who have a hard time organizing around writing, and the kinesthetic and oral learners because they've had a great hands on experience with many senses being used and then they get to write about it.

Based on participating teachers' and independent reviewers' comments on the effectiveness of these strategies, it seems reasonable to infer that teachers involved in the program may have developed higher expectations for ELL students and student below grade level by using the approaches and by observing that that they support the learning of these students.

Figure 2.**PERCENTAGE OF TEACHERS REPORTING THAT WRITING IN SCIENCE IS HELPFUL FOR PARTICULAR GROUPS OF STUDENTS**

Percentages represent teachers who marked “4” or “5” on a 5-point scale where “1” = “not at all helpful” and “5” = “very helpful.” The result for ELL students is statistically significant at $p=.03$.

State standards and assessments

- ◆ **The curriculum strand and teaching practices of the Expository Writing and Science Notebooks Program are consistent with state standards and appear to help students meet standards and prepare for standardized assessments.**

Independent reviewers noted that the program is consistent with state standards and appears to help students address and meet several standards:

What these kids are doing is exactly what we want them to be doing in the state of Washington. The curriculum is appropriate and aimed at both the essential learning and the kinds of ways of demonstrating knowledge that we are interested in, and I think it is exactly what we want.

And then with scientific thinking and science being sort of the third standard, I think these notebooks provide a lot of evidence [of students] thinking about their observation, interpreting data, descriptive writing, all of that is very evident. So it is very standards-based as far as science.

They note especially that it is the combination of writing and science that helps students meet standards:

They are having a lot of opportunity to meet both science and writing standards. They note further that the types of prompts used are likely to prepare students to be able to respond to a range of on-demand writing assessments. An out-of-state expert noted that the work is also consistent with their state standards, especially for expository writing development.

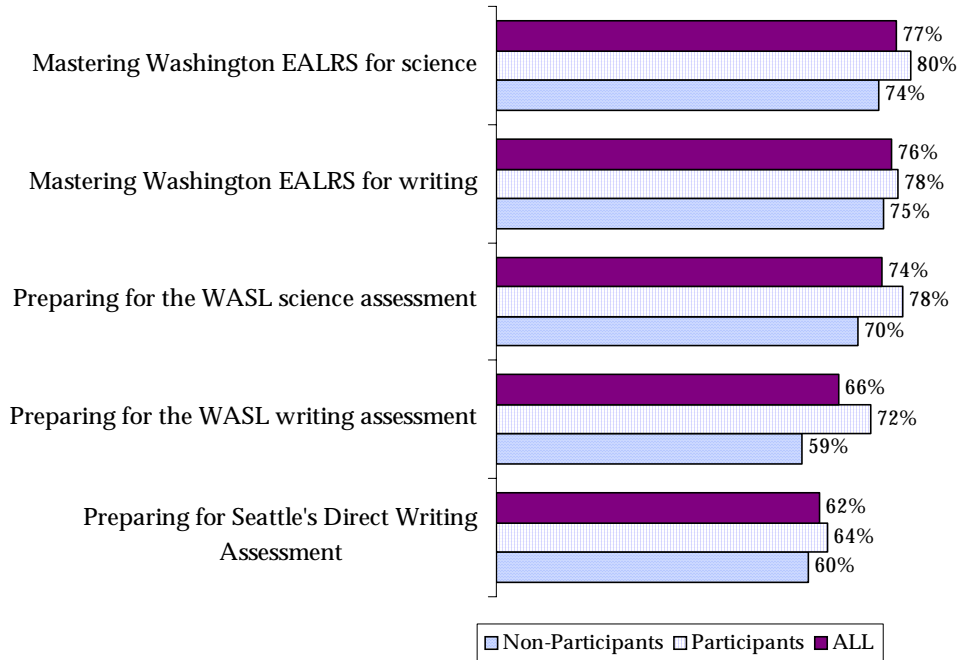
Some teacher reviewers noted that if students were also to be invited to design their own investigations, additional standards would be met:

And while this would not be a reason to drive instruction, what I saw in these notebooks is exactly what they are looking for on the 5th grade science WASL, except they weren't asked to set up their own investigations.

Teachers responding to the survey also report in substantial proportions that the writing approaches learned in the Science Writing classes help them help students meet standards and prepare for standardized assessments. The graph below shows that there are differences between the perspectives of participants and non/limited-participants, with more participants believing in the value of the program for helping students meet science content standards (Essential Academic Learning Requirements, or EALRs) and to prepare for the science and writing tests for the Washington Assessment of Student Learning (WASL).

Figure 3.

PERCENTAGE OF TEACHERS REPORTING THAT TEACHING WRITING IN CONNECTION WITH SCIENCE IS HELPFUL FOR PREPARING FOR AND MASTERING VARIOUS ASSESSMENTS



Percentages represent teachers who marked "4" or "5" on a 5-point scale where "1" = "not at all helpful" and "5" = "very helpful." The result for "preparing for the WASL writing assessment" is statistically significant at $p=.041$.

Trade-offs related to teaching writing in science

- ◆ **For many teachers, the advantages of having students write in science mitigate, but do not dispel, the challenges of finding time to write and balancing students' multiple needs.**

On the written survey participants and non/limited-participants alike see many more advantages than disadvantages to teaching writing in science. A good number of them, however, find they are making serious trade-offs by emphasizing writing. A total of 161 teachers (over half of those who responded) wrote comments about the "downsides" of teaching writing in science; of them, fully 108 state the time required as the major disadvantage. Other themes include concern about reducing children's excitement of science and the developmental levels of students in terms of motor skills and literacy. A sample:

- More volume of reading work to assess, besides other writing going on in classroom.
- There is now competition for teachers' evaluative time.
- Most of my students don't like to write. I think they've begun to dread science because it means yet more writing.
- The time it takes for them to write. It's hard to balance letting them do their experiments and wanting them to get their entries in.
- Time is the enemy.
- Time.
- TIME.

B. Current Level of Student Competence in Relation to Program Goals

Besides asking reviewers to assess the student work from the perspective of their own expertise, expectations and standards, we wanted to assess the same sample of 60 notebooks in a rigorous way against the standards of the Expository Writing and Science Program itself. Fifteen teachers who are not part of the program read and gave scores to these notebooks. They followed a rubric that was piloted in our 2002 study. The rubric reflects four levels of competence within each of three criteria that reflect program goals for student learning. The table below summarizes the criteria and levels of competence; in the appendix is the rubric that was used, complete with detailed descriptors of each level within each criterion.

Table 1.
Summary of Criteria and Levels in Scoring Rubric

Criterion	Level			
	1	2	3	4
Conceptual development and understanding of "big ideas" of unit	limited	developing	adequate	full
Scientific thinking and purposeful use of inquiry skills and processes	limited	developing/ partial	adequate	skilled/ purposeful
Expository writing—development, organization, word choice	limited	developing	adequate	fluent and skillful
Total Scores	3	6	9	12

Each reader assigned a score of 1-4 for each of the three criteria, and each notebook then received a summed score of 3-12. Each notebook was read independently by two readers. If there were one-point differences between their scores, they were averaged. If there were two-point differences, the differences were reconciled by the table leaders.

Ratings across grade levels and criteria

- ◆ **On a 12-point scale, with 12 reflecting "full" competence and 9 reflecting "adequate" competence, the student notebooks received overall scores between 7 and 9. Scores for 5th grade were highest, 1st grade next and 3rd grade lowest.**

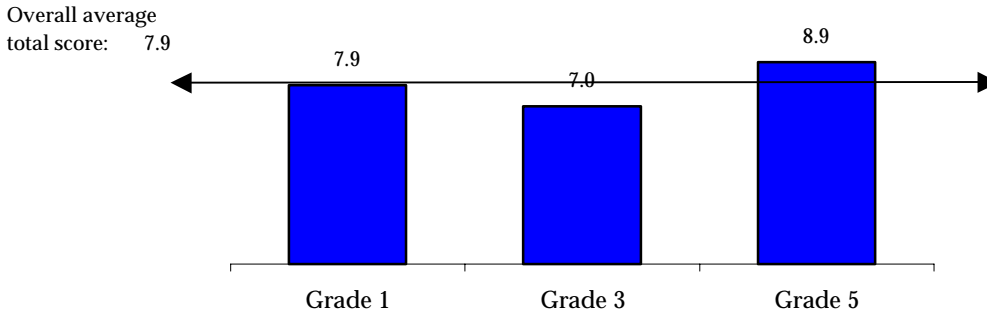
The graphs on the following page display the results of the scoring. Total scores hover in the 7-9 range, which suggests that on average, the sampled groups are just shy of, but close to, the “adequate” level of 9.

Scores for 5th grade were highest, 1st grade next and 3rd grade lowest. There are two explanations for this, both seemingly reasonable. The scorers, on reflection, attributed the lower 3rd grade scores in part to the particular science unit, which has less conceptual complexity, relative to grade level, than either the 1st or 5th grade unit. They also suggested that the writing component for the 3rd grade may itself have been slightly weaker than in the other grades because, at least in this sample, the notebooks exhibited less use of focus questions and also less use of prompts that would invite students to develop the conceptual content that did exist in the unit. It is in this unit that readers believe a stronger writing curriculum could enhance the quality of the unit. Alternatively, the difference in scores may reflect natural differences in student development related to the time of year the units were taught. Notebooks from the 1st and 5th grade units are from the Winter term, when the students were studying the second science unit of the three they would study during the year, while 3rd grade notebooks are from the Fall term and reflect the students’ first work in science for the academic year.

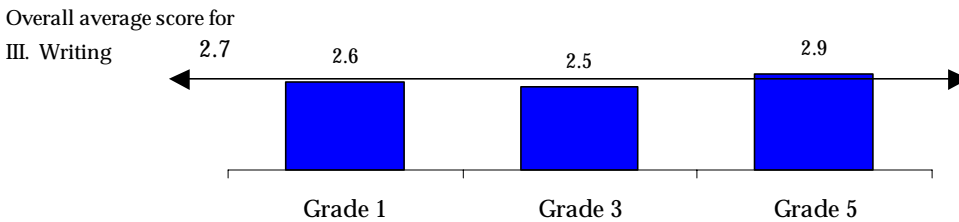
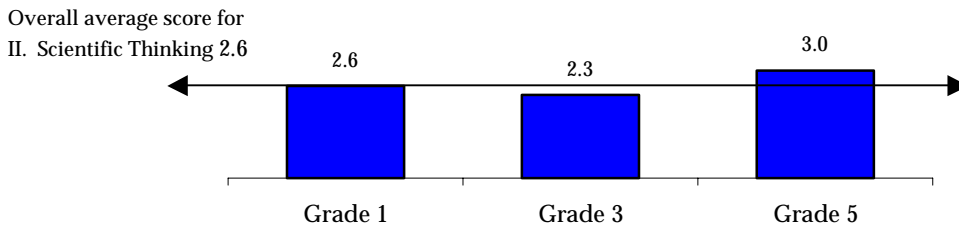
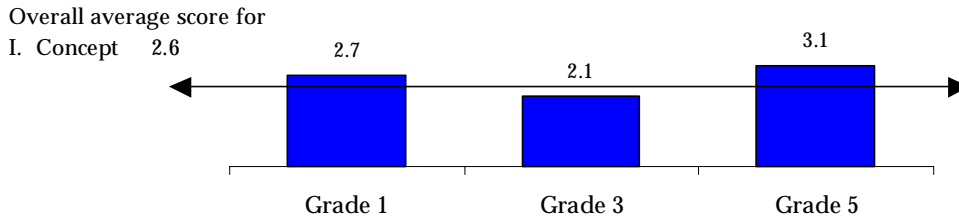
The samples are too small to make statistical comparisons between students with different characteristics (ELL, Special Education designation, etc.). As we note above, independent reviewers, as well as respondents to the teacher survey, indicate that the writing program appears to serve a range of students, including those with special needs.

Figure 4.

**Independent Teacher Ratings
Comparison of total scores by grade**



**Independent Teacher Ratings
Comparisons of scores for each criteria by grade**



C. The Quality and Value of the Professional Development

In this section we report findings primarily from the teacher survey, where teachers rated the value of professional development provided by the Expository Writing and Science Notebooks Program and comment on the specific features that give it value. We also include some comments from independent reviewers of notebooks who could infer the presence and quality of the professional development by reading several notebooks.

Characteristics of SPS elementary science teachers

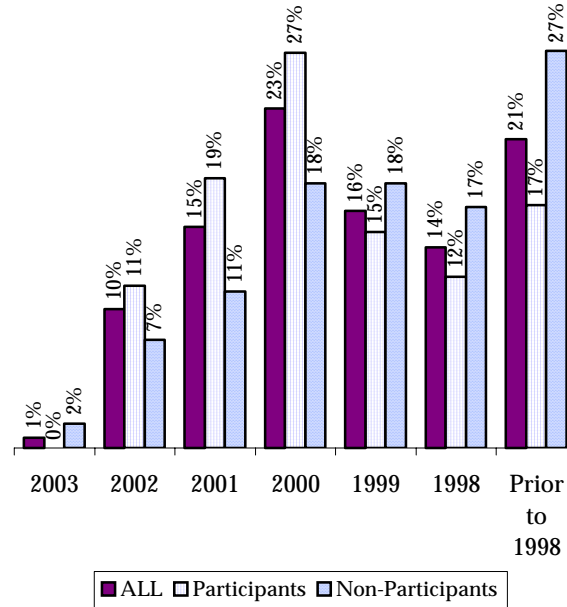
- ◆ **Participants in the Expository Writing and Science Notebooks Program are somewhat less experienced as science teachers than non/limited-participants, started teaching the district science units more recently than non/limited-participants, and participated in the Science Writing classes around the same time they started teaching the science units.**

Results of the teacher survey show that participants in the Writing program are somewhat less experienced as science teachers overall than non/limited-participants: 41% of participants say they have been teaching science for 3 years or less, compared to 27% of non/limited-participants. Participants have also been teaching at their schools for fewer years: 46% of participants have been at their school for 3 years or less, compared to 33% of non/limited-participants. Further, participants in the Writing Program are substantially more likely to have started teaching the science units more recently than non/limited-participants, and to have experienced the Science Writing classes around the same time they started teaching the science units. The graph below shows that a total of 57% of participants started teaching the district's science units in the year 2000 or later, compared to 38% of the non/limited-participants. About 62% of non/limited-participants in the Writing Program started teaching the districts units in 1999 or earlier, compared to just 38% of participants.

Together, these results suggest that for a substantial proportion of participants in the Expository Writing and Science Notebooks Program (those who are newer to teaching), the professional development in both the science units and the writing strand were consistent with one another and worked together to provide them with materials, knowledge, and strategies related to teaching science.

Figure 5.

YEAR BEGAN TEACHING SCIENCE USING DISTRICT ADOPTED MATERIALS
(PERCENTAGE OF TEACHERS REPORTING)



Overall quality of the professional development

- ◆ **The professional development offered in the Expository Writing and Science Notebooks Program is highly valuable to teachers, often more valuable than other professional development.**

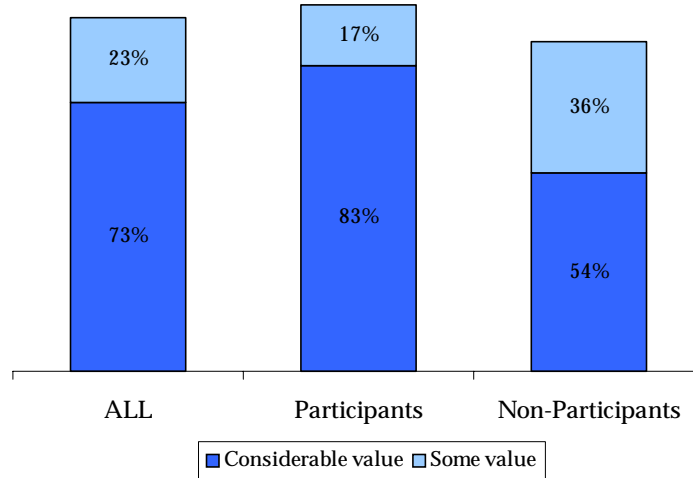
The survey results show that Seattle teachers hold the Expository Writing and Science Notebooks professional development classes in very high regard. The graph below shows that among those designated as participants,¹³ fully 83% report that they are of considerable value, and the remaining 17% say they are of some value. Among those designated as “limited/non-participants,” 54% of those who have participated in any¹⁴ say they have considerable value, and another 36% say they have some value.

¹³ Recall that teachers who had participated in two or more workshops within the past three years were designated as participants. A substantial proportion of the “non/limited-participants” have participated in 1 workshop within that period or more than two during the full tenure of the program.

¹⁴ For survey items that asked about the value and quality of the writing classes, the *n* of responses from the “non/limited participant” group was much smaller than for the other items

Figure 6.

OVERALL VALUE OF THE SCIENCE WRITING CLASSES AS PROFESSIONAL DEVELOPMENT
(PERCENTAGE OF TEACHERS REPORTING)



On the survey, we also asked teachers to compare the Expository Writing classes to other professional development, both within the elementary science program (LSC project) and from other sources. For most comparisons, there are differences between the participants' and non/limited-participants' perspectives, with participants reporting that the writing classes are more valuable than other professional development.

The graph on the following page shows that participants are more likely than non/limited-participants to report that the Writing classes are more valuable than the LSC's Initial Use classes (46% for participants, 29% for non/limited-participants) and the Content classes (50% vs. 35%).¹⁵

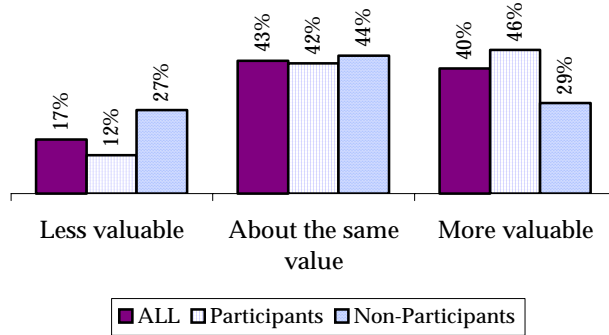
(~70-90 instead of ~125-133) because only those individuals who actually had taken a class responded. The tests of statistical significance take this difference in *n* into account.

¹⁵ We wish to note that we were asking teachers to compare types of classes within a professional development program for the teaching of science that is overall of good quality and strong coherence, and which has taken steps to offer a wide range of courses that appeal to teachers' varying interests and needs over time. Please see our Spring 2002 report, "*Seattle Partnership For Inquiry-Based Science: A Local Systemic Change Initiative - End-Of-Project Report.*"

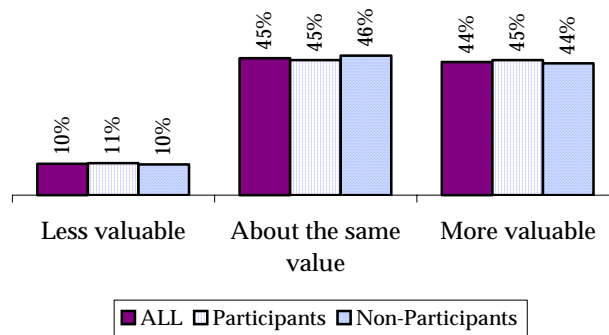
Figure 7.

**VALUE AND USEFULNESS OF THE SCIENCE WRITING CLASSES AS COMPARED TO OTHER PROFESSIONAL DEVELOPMENT OFFERED BY THE LSC
(PERCENTAGE OF TEACHERS REPORTING)**

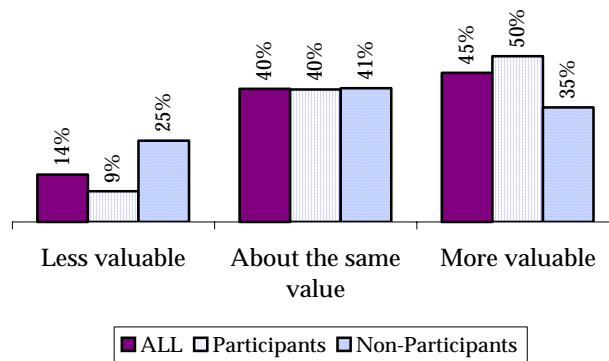
INITIAL USE CLASSES – INQUIRY BASED SCIENCE



DATA ANALYSIS: EXPLORING DATA WITH ELEMENTARY CHILDREN



INQUIRY-BASED SCIENCE CONTENT COURSES (FOR GRADE LVL SCIENCE UNITS)



Results for Initial use classes and Science content courses are statistically significant at p=.001 and .002 respectively.

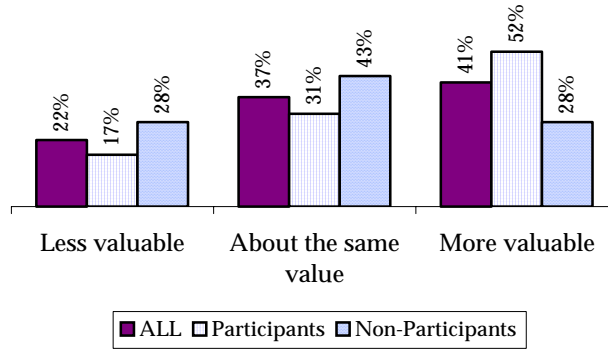
In comparing the value of the Expository Writing classes with professional development in science and in writing from sources *other than* the Seattle LSC, the survey results show that for all three comparisons, participants are more likely than non/limited-participants to assign greater value to the Expository Writing classes than to professional development from other sources. The contrast between the two groups is greater for comparisons between the Expository Writing classes and other *science* professional development than for other professional development in *writing*. Among participants, 52% say that the Expository Writing classes are more valuable than other science professional development, compared to 28% of non/limited-participants. For comparisons between the Expository Writing classes and other professional development in writing, the difference between the two groups is smaller: 52% of participants, compared to 40% of non/limited-participants, say the Writing classes are more valuable than other professional development in writing offered by the district; and 43% of participants, compared to 34% of non/limited-participants, say the Writing classes are better than professional development in writing that they receive from sources outside the district. These results indicate that the Expository Writing classes are indeed supporting teachers' professional development in service of both subject areas (science and writing), not only science.

The graph is on the following page.

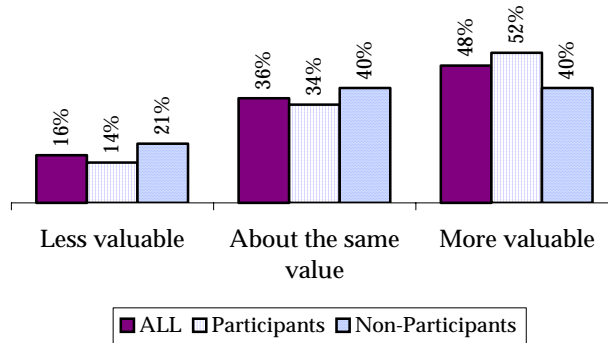
Figure 8.

VALUE AND USEFULNESS OF THE SCIENCE WRITING CLASSES AS COMPARED TO PROFESSIONAL DEVELOPMENT OFFERED FROM OTHER SOURCES
(PERCENTAGE OF TEACHERS REPORTING)

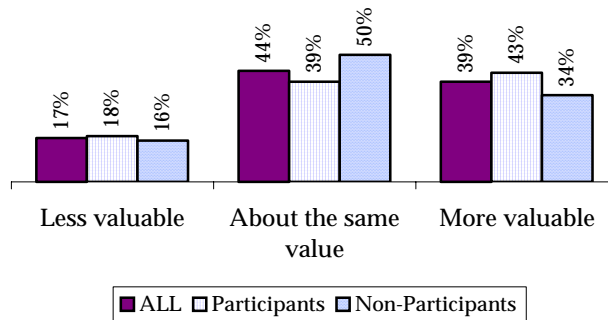
VALUE COMPARED TO OTHER PROFESSIONAL DEVELOPMENT IN SCIENCE FROM SOURCES OUTSIDE THE DISTRICT



VALUE COMPARED TO OTHER PROFESSIONAL DEVELOPMENT IN WRITING OFFERED BY THE DISTRICT



VALUE COMPARED TO OTHER PROFESSIONAL DEVELOPMENT IN WRITING FROM ANY SOURCE OUTSIDE THE DISTRICT



The effect of the professional development on teachers' practice

- ◆ **The classes offered by the Expository Writing and Science Notebooks Program provide teachers with specific, applicable teaching strategies that enhance their ability to teach science and writing in systematic ways.**

By reading a sample of several notebooks, independent reviewers could infer the existence of a professional development program that is enabling teachers to improve their teaching of the science units—and to improve the units to the extent that the resulting student work is distinctively better than work they have seen elsewhere. They emphasized that student work such as what they were seeing in these notebooks does not happen by chance.

[In the student notebooks I saw] a gamut of abilities that I think definitely exceeded my expectations. It was clear, even in the structure where the student will have circled the appropriate word to concentrate on in the focus questions, that the teachers had undergone special professional development, and so [this work] is not something that I would expect to see in other classrooms, outside of Seattle.

It is clear that the work of the teacher shines through this – that is not something that [happens] spontaneously when you just work with a science kit, or just pass out the notebook with the kit.

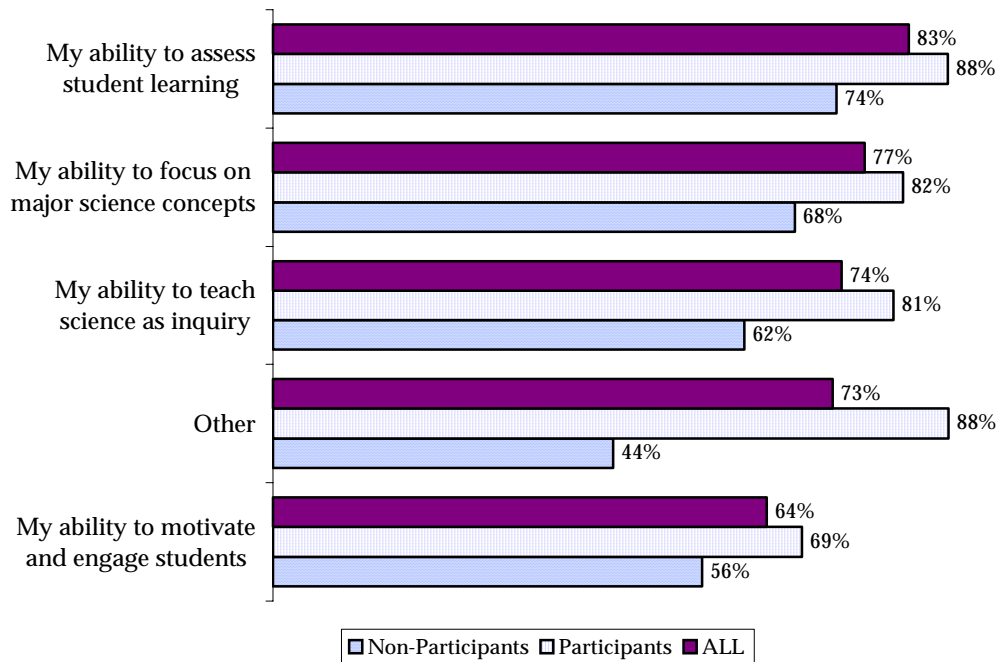
The occasional notebook that lacked strong student writing stood out as a contrast, again causing reviewers to infer the presence of specific teaching practices in the great majority of the notebooks:

In certain notebooks you could tell, they were asking questions about pollination, and the kid answered it, and in other notebooks, the teacher didn't ask that and the kids didn't mention that at all. I noticed that it really depends on what questions [the teacher asks].

On the survey we asked teachers about the ways in which the professional development enhanced their ability to teach science. The graph below shows that participants say they are more able to assess student learning, focus their teaching on important science concepts, teach science as inquiry, and motivate and engage their students because of the Science Writing classes.

Figure 9.

**PERCENTAGE OF TEACHERS REPORTING WAYS IN WHICH THE SCIENCE WRITING CLASSES
HAVE ENHANCED TEACHING OF DISTRICT SCIENCE UNITS**



Percentages represent teachers who marked "4" or "5" on a 5-point scale where "1" = "greatly diminished" and "5" = "greatly enhanced." For each of the four comparisons, results are statistically significant at $p < .005$.

The survey form invited teachers to enter open-ended comments on the value and benefits of the Expository Writing classes. Fully 95 of the participants took the time to write comments. The following are a representative sample. It is clear that the classes offer concrete, relevant, and applicable strategies that strengthen teachers' skills and enhance their confidence in teaching the science units:

- I find the writing in science classes much more valuable because it is geared toward my grade level and specific units I will teach. Other professional development classes in writing are broad and do not always apply to your grade level.
- It was focused on units I have done and will do in the future. I could ask questions which directly concerned me about how I deliver instruction.
- The instructor believes in her materials, shares anecdotal stories, knows the kits, has clearly taught the kits and writing in science, is clear, thorough, organized, and allows discussion and conversation to take place to clear up questions. This process has been the best training I have had to date.

- I am able to actively use it with students. Also because it is an area (non-fiction/expository writing) where I have not been trained before I found it very useful and engaging. Unlike other classes this felt like new info rather than a repeat of what I know.
- I feel that the Science writing causes attached issues/problems and were immediately applicable. They helped me better understand the conceptual understanding. Initial use is just an intro, and were often missing holes in unit or did not fully provide adequate time to fully understand.
- Writing in Science allows students to really process what they studied in a lesson and makes them express what they've learned. It is a good way to check student learning throughout a unit so I can re-teach if needed.
- This has been a real life saver when I was a first year teacher!
- The district science program is one of the few really wonderful aspects of the academic program here.

D. Implementation of District Science Program and Writing in Science

On our survey, we asked teachers to report on the extent of their teaching of the district's science curriculum (irrespective of the writing component), as well as the extent to which they teach writing in science. Most of the findings in this section are from the survey. Additionally, independent reviewers made inferences about implementation from reading student notebooks from multiple classrooms.

Consistency of approach across classrooms

- ◆ **The sample of notebooks from the Lead Science Writing Teachers' classrooms shows evidence of a consistent approach that can have cumulative benefits for students as they advance through the grades.**

Offering students consistency in instruction across grade levels is an important educational concern. Outside reviewers, including those familiar with science programs in a range of schools and districts beyond Seattle, say that the student work in the sample of Seattle notebooks demonstrates the presence—in all 6 classrooms reflected in the sample—of a well-scaffolded approach to teaching writing in context of hands-on science:

It reflects a national concern in terms of a level playing field for students who are in classrooms and as they progress through a system... the experience is consistent throughout all of the grades, and that is one of the parameters that really affects student performance. Consistency was evident [in the notebooks], consistency in instructional approach. I found it in the expectations. I saw an interesting progression of scaffolding as I moved through the notebooks, but I think the real value is having an articulated consistent approach in every classroom, and that speaks of professional development.

All of the kids are consistent which would mean that the teacher would have to be consistent in making sure that that happened...They [the notebooks] came from different classrooms and it looks like there has been training for the teachers in how to implement science notebooks.

Extent of implementation of district science units

- ◆ **All teachers responding to the survey report teaching 2.8 science units per year, on average. Participants in the Expository Writing and Science Notebooks Program teach more exclusively from the district curriculum, spend more time teaching science, teach more lessons from the units, and are more likely to increase their teaching of science from year to year.**

Results of the teacher survey suggest that overall, there is a substantial—and impressive—degree of implementation of the district science curriculum, with participants and non/limited-participants saying that they teach 2.8 units per year (expectations are to teach 3). Participants in the Writing Program are different from non/limited-participants, however, in that on average they teach more lessons per unit, teach science more days per week, spend more time on science, and focus their science more exclusively on the district curriculum. Participants are also more likely than non/limited-participants to increase their teaching of science from one year to the next and to teach more science than others in their school.

In the table on the following page, we present the results of 8 survey items that ask teachers to report, in various ways, on the extent to which they implement the district's science curriculum. The column on the right reflects the overall degree of implementation of all respondents.

Table 2.**THE EXTENT OF IMPLEMENTATION OF DISTRICT SCIENCE CURRICULUM**

Implementation of science curriculum	Participants in Writing Program	Non-Participants	All
a. Number of district science units taught per year (full implementation would be 3 units)	2.8	2.8	2.8
Proportion of science curriculum that comprises district units			
-Classroom science curriculum is entirely district-based	87%	71%	80%
-District units are one of several components of classroom science curriculum	12%	26%	18%
Percentage of teachers who teach "most or all" of the lessons in the units	87%	77%	82%
Number of hours spent on teaching the units	20 (median)* 102 (mean)	15 (median) 47 (mean)	16 (median) 78 (mean)
Percentage of teachers who teach science:			
3-5 days a week	54%	44%	50%
2 days a week	36%	38%	36%
**Number of minutes per week spent on science	120 (median) 127 (mean)	100 (median) 108 (mean)	120 (median) 119 (mean)
Percentage of teachers who taught more science this year than last year	29%	16%	23%
**Percentage of teachers who believe they teach more science than other teachers in their school	40%	30%	36%

** A large difference between the mean and the median indicate a very wide spread in the range of answers. In this case, the median is probably a more illustrative statistic than the mean. For the number of minutes per week, the median and mean are quite close together, which offers a more robust result.*

*** Differences for these items are statistically significant at $p < .03$*

Extent of teaching writing in science

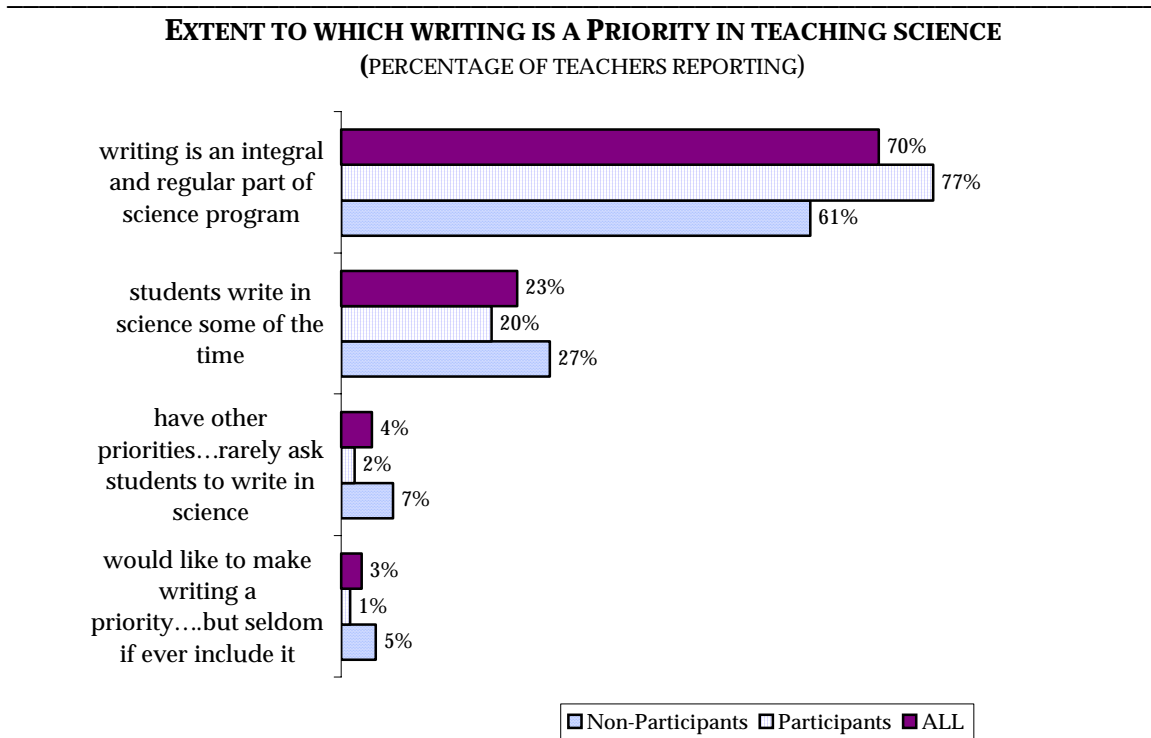
- ◆ **Teachers participating in the Expository Writing and Science Notebooks Program are substantially more likely than non/limited-participants to place a priority on writing in science, to implement the approaches they gained from the program, and to spend more time on writing in science. However, a notable proportion of other teachers are also inclined to teach writing in science.**

On our survey we asked teachers to report on the priority they placed on writing as part of their science curriculum and on how frequently they use writing in science, including the specific prompts and strategies of the Expository Writing program. As might be predicted, participants

are more likely to place a priority on writing and to implement the approaches of the writing program. However, a notable percentage of non/limited-participants are also somewhat inclined to teach writing in science and even to use some of the prompts from the Writing Program.¹⁶

The graph below portrays the extent to which participants and non/limited-participants place a priority on writing in science. Although participants place a higher priority on writing (77% say it is integral), we also note that 61% of non/limited-participants also say it is a regular part of their program.

Figure 10.

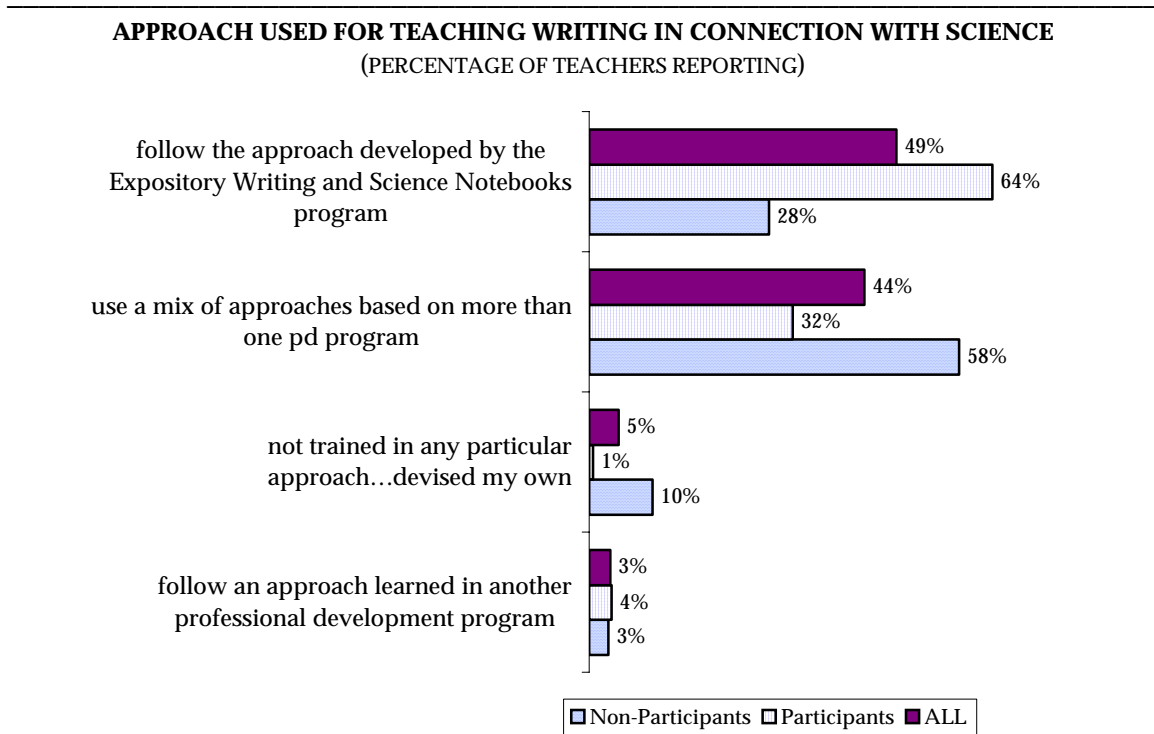


Differences for the first two statements are statistically significant at $p=.001$.

The survey also asked teachers about the extent to which they implement the specific approaches of the Expository Writing and Science Notebooks program when they ask students to write in science. Predictably, participants say that they follow the program with greater fidelity, although 28% of non/limited-participants say they also follow the approaches.

¹⁶ Again, recall that some respondents defined as “non/limited-participants” have in fact taken a Writing Class; also some of them teach next door to committed participants. Further below in this section, we report respondents’ perspectives on what factors influence them to teach writing in science.

Figure 11.



Differences for the first two statements are statistically significant at $p=.002$.

In the table on the following page, we compile the results of several survey items that ask about the extent to which teachers include writing in science. The pattern is that participants teach writing in science to a greater extent than non/limited-participants.

Table 3.**THE EXTENT OF THE TEACHING OF WRITING IN SCIENCE**

Teaching Writing in Science	Participants in Writing Program	Non-participants	All
**Proportion of science lessons where students are asked to write	75% (median) 67% (mean)	50% (median) 51% (mean)	65% (median) 60% (mean)
**Percentage of teachers who have students write in science: 3-5 days a week 2 days a week	30% 45%	18% 38%	24% 42%
**Number of minutes per week in which students write in science	40 (median) 47 (mean)	30 (median) 37 (median)	40 (median) 43 (mean)
**Percentage of science lessons where Teachers used prompts from the Expository Writing program	80 (median) 70 (mean)	30 (median) 39 (mean)	65 (median) 60 (mean)
Percentage of teachers who spend more time on writing in science than other teachers in their schools	53%	35%	45%
Percentage of teachers who spend more time on writing in science this year than last year	51%	45%	49%

***Differences for these items are statistically significant at $p < .003$*

We note here that this study did not include independent or empirical assessment of the quality of implementation of the program's approaches. The teachers responding to the survey have received less professional development support than the Lead Science Writing Teachers (LSWT) from whose classrooms we drew the notebooks. We believe it is reasonable to infer that in the classrooms of the typical participant, students are experiencing some benefits of the program's approach but not to the same degree as students in the more experienced LSWT classrooms.

Enhancement of curriculum in other areas

- ◆ **The curriculum strand and teaching strategies of the Expository Writing and Science Notebooks Program have some benefits to teaching and learning in other subject areas. The writing strand serves well as a partial (not full) writing curriculum.**

Outside reviewers and teachers alike also found positive links between the Science Writing program and other curriculum areas. In the context of some units and lessons, for example, the student work in science notebooks showed evidence of purposeful use of mathematics skills or a connection to reading literacy.

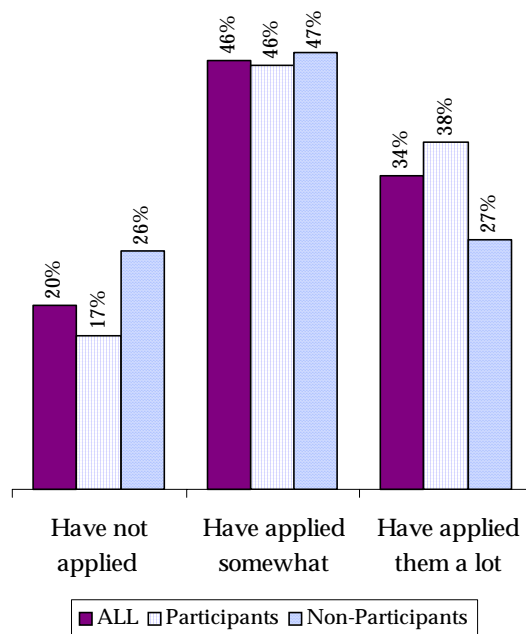
On the survey, a substantial number of teachers reported that they have applied strategies learned in the Science Writing classes to their teaching of other subjects. Again, we find that non/limited-participants report doing this, though less frequently. These results are shown on the graph below.

In their written comments on the survey, participants explain the benefits across the curriculum:

- Reinforcing writing skills, demonstrates the importance of writing in other subjects.
- Showing students that writing isn't a separate subject- it's used across the curriculum and in everyday situations.
- The thinking, evaluating, observation process involved with writing in science carries over to other subject areas.

Figure 12.

**EXTENT TO WHICH TEACHERS HAVE APPLIED WRITING APPROACHES LEARNED FROM
SCIENCE WRITING CLASSES TO OTHER SUBJECT AREAS**
(PERCENTAGE OF TEACHERS REPORTING)



The difference between the two groups in "applied them a lot" is statistically significant at $p=.043$.

There is only one caveat to the reviewers' enthusiasm about the application of the Science Writing program across the curriculum. They note that the writing approach, though very effective for expository writing in a content area, is a partial writing curriculum for a school or district, not a full writing curriculum. As one reviewer put it:

It [the writing approach] is narrow, but that is not necessarily bad. If this were all there were to writing, okay, we have a problem, but this isn't.

Amid the overwhelming positive views teachers have, some do not want the Expository Writing and Science Program to offer their only avenue for development in the teaching of writing. On the teacher survey, a participant made this comment:

I was enrolled in the Puget Sound Writing Project at the UW for two summers and NUA with the district. Both programs offered more variety and options in writing - including creativity - than I learned in Expository Writing and Science Notebooks.

Factors that influence teachers' use of writing in science

- ◆ **For participants in the writing program, the available materials for teaching science, the amount of professional development for writing in science, and beliefs about the of writing in science are the three strongest factors enabling them to teach writing in science. For non/limited-participants, all three are weaker factors. There is also a significant difference between groups in the emphasis given to writing in science at the teachers' schools, but this is not a strong factor. For teachers in both groups, time is the greatest constraint.**

On the survey we asked teachers to indicate what factors contribute to, and constrain, their teaching of writing in science. We included personal factors such as beliefs and knowledge, as well as contextual conditions such as school and district emphasis on science and writing, and the availability of professional development.

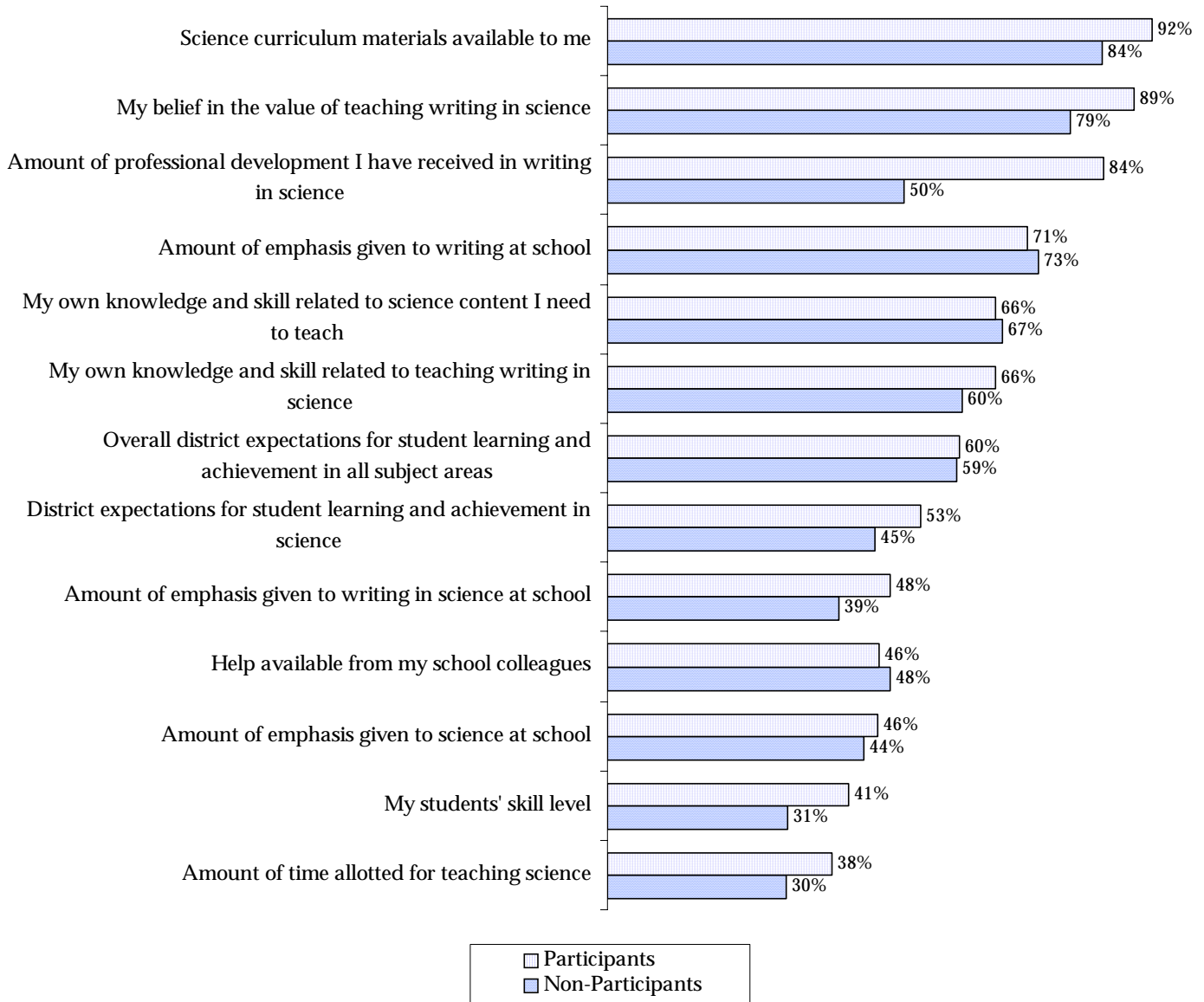
The graph on the following page shows that although there are many similarities in the factors that influence all teachers, there are significant differences between the two groups. For participants in the writing program, the available materials for teaching science, the amount of professional development for writing in science, and beliefs about the value of writing in science are the three strongest factors enabling them to teach writing in science. There are statistically significant differences between the two groups on these factors. This result reinforces the fact that the science and writing programs go hand-in-hand; that is, that the writing program is an enhancement of the foundational science program. Teachers' comments on the written survey offer further evidence of this:

- Kits are replenished and kept in good order, science notebooks supplied. The science writing instructor has been very helpful.
- The science writing classes have been a great help. These skills carry over into other areas.

For non/limited-participants, the graph shows that professional development in writing is a considerably weaker factor; other modest differences between the two groups are the influence of personal beliefs about the teaching of writing and expectations related to students' skill level, as well as the influence of school expectations for writing in science and district expectations for science in general.

Figure 13.

FACTORS REPORTED AS AN ASSET FOR TEACHING WRITING IN SCIENCE
(PERCENTAGE OF TEACHERS REPORTING)



Differences for the following are statistically significant: Science curriculum materials given to me (p=.003); my belief in the value of teaching writing in science (p=.008); the amount of professional development I have received in writing in science (p=.000); and amount of emphasis give to writing in science in my school (p=.046.)

Both groups have in common a deep, abiding frustration that there is not enough time to teach science as well as they would like or well enough to fulfill district expectations. For many, teaching hands-on science, much less having students *write* in science, means taking time from other priorities. A total of 52 teachers wrote about constraints, and 29 named lack of time. Representative comments:

- 3 kits difficult to complete given all the other things we must fit in, especially when writing is included. Little time for extensions, exploration. Classroom facilities, amount of space that must be taken by science materials, no large sink area. Prep and clean up very time consuming.
- Math has taken time from Science. Our principal has said to do math 60 min. per day. No time for Science. Help please. I have lost faith in Admin. They talk out both sides of the mouth.
- Time
- Time!
- Time, time, time!

** ** * * * * *

In summary, we note that these data from multiple sources add up to a quite extraordinary portrait of and statement about the Expository Writing and Science Notebooks Program. Outside reviewers who reflect multiple perspectives in education—classroom teachers, school administrators, science education faculty, leaders of policy and school reform initiatives—find that the Seattle student notebooks reflect approaches to the teaching and learning of science and writing that the field believes are valuable but that are rarely observed in actual practice in schools and districts. The teachers participating in the program appear to be strongly committed to it, often in the face of competing pressures. When one considers that, for many teachers defined as “participants,” the formal professional development experience consisted of from two to four 90-minute workshops, it is impressive indeed that so many teachers report the professional development as being so valuable and report that they are using the strategies so frequently in their classrooms.

V. REFLECTIONS ON THE EDUCATIONAL SIGNIFICANCE OF THE EXPOSITORY WRITING AND SCIENCE NOTEBOOKS PROGRAM

The Expository Writing and Science Notebooks Program, as an enhancement of a progressive hands-on science program, is a rare example of an important idea being put into practice. In our experience studying professional development initiatives, observing quality at a small scale *and* significant movement toward implementation at a district scale is quite rare.

Contributions to educational improvement

The results of this study suggest that the Expository Writing and Science Notebooks Program is making a significant contribution to educational improvement in two ways:

First, the program is enhancing the K-5 elementary science program at the level of classroom practice and at what appears to be a substantial scale across the district. It is thus making a significant positive contribution to the Seattle Public Schools.

Second, the Expository Writing and Science Notebooks Program is a visible instantiation of one answer to an educational question that the field deems significant: How can writing and science serve one another in classroom instruction?¹⁷ The approach is well-specified through curriculum for writing that is linked to existing science units, and for which there is a coherent professional development component. These design features give it potential to be adaptable to other district contexts. The program is thus serving the broader field by providing an example of an approach to teaching writing in science, and science in writing, that appears to be both feasible to implement and largely beneficial to teachers and students.

Further development and sustainability

There are some ways the program can continue improving, and some challenges that it faces.

Expansion of writing curriculum. Our study this year turned up the same area that needs improvement as the 2002 study: that is, the need to include more explicit support for student-generated, student-structured writing. This improvement in the writing program would also enhance the inquiry component of the science program because some of the student-generated writing could be linked to student-generated scientific study.

Extension and distribution of leadership for professional development. The Expository Writing program's capacity to provide professional development is limited because, to our knowledge, there is just one individual who leads the professional development classes. Further, the Lead Science Writing Teachers most nearly qualified to begin teaching Writing classes are among the same individuals who are teaching Initial Use classes for the science units, and their personal capacity to serve in these roles is limited. This "cap" on leadership may limit opportunities for teachers new to the approach, and certainly limits participating teachers' access to the kinds of ongoing learning opportunities that are enjoyed by the Lead Science Writing Teachers and that can increase teachers' effective implementation of the approach. (We note that as of 2002-03, some non-LSWTs have been invited to participate in the study-group-style LSWT meetings, giving a few teachers structured support beyond the classes.) We believe that a plan for distributed and extended leadership would help ensure the long-term sustainability and growth of the program.

If the program were able to demonstrate an effective strategy for expanding and distributing leadership responsibility, other districts interested in adopting the program might have greater potential to learn how to develop internal leadership.

Sustainability of the program in the context of district stresses and priorities. We remain concerned about the district's lack of direct financial support for the program, given the benefits that accrue to students, teachers, and the district as a whole. We are also concerned that district priorities for student achievement may continue to put elementary teachers in the position of

¹⁷ Indeed, we at Inverness Research Associates have received requests, and we know the project has also, for information related to introducing the Seattle Expository Writing and Science Notebooks approach in other districts. And at the end of the scoring session involving outside teachers, a teacher asked: "When are they giving this course? I want to sign up for it!"

giving short shrift to science or feeling as if they are displacing other priorities when they teach science. It is not clear the extent to which the science WASL will raise the visibility of science as a priority, but it could conceivably do so.

While these challenges are significant, we want to emphasize that on the whole, the Expository Writing and Science Notebooks Program appears to be a remarkably solid and effective program that makes a difference for teachers and students in the Seattle Public Schools and that serves as a model for others.

REFERENCES

- Bass, K. M., Baxter, G. P., & Glaser, R. (2001, April). *Using reflective writing exercises to promote writing-to-learn in science*. Paper presented at the annual meeting of the American Educational Research Association, Seattle, WA.
- Greenbowe, T. J. (2002, September). *What our students tell us when they write explanations about chemistry*. Paper presented at the international conference Ontological, Epistemological, Linguistic and Pedagogical Considerations of Language and Science Literacy: Empowering Research and Informing Instruction, Victoria, BC, Canada.
- Hand, B. M., & Prain, V. (1995). Using writing to help improve students' understanding of science knowledge. *Science Education*, 77, 112-117.
- Hildebrand, G. M. (1998). Disrupting hegemonic writing practices in school science: Contesting the right way to write. *Journal of Research in Science Teaching*, 35, 345-362.
- Holliday, W. G., Yore, L. D., & Alvermann, D. E. (1994). The reading-science learning-writing connection: Breakthroughs, barriers, and promises. *Journal of Research in Science Teaching*, 31, 877-893.
- Kelly, G. J., & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education*, 86, 314-342.
- Keys, C. W. (1994). The development of scientific reasoning skills in conjunction with collaborative writing assignments: An interpretive study of six ninth-grade students. *Journal of Research in Science Teaching*, 31, 1003-1022.
- Keys, C. W. (1999). Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science. *Science Education*, 83, 115-130.
- Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching*, 36, 1065-1084.
- Keys, C. W. (2000). Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *Journal of Research in Science Teaching*, 37, 676-90.
- Kirkpatrick, L. D., & Pittendrigh, A. S. (1984). A writing teacher in the physics classroom. *The Physics Teacher*, 22, 159-164.
- Klein, P. D. (1999). Reopening inquiry into cognitive processes in writing-to-learn. *Educational Psychology Reviews*, 11, 203-270.

- Klein, P. D. (2000). Elementary students' strategies for writing-to-learn in science. *Cognition and Instruction*, 18(3), 317-348.
- National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.
- Merino, B. J. (). How do teachers facilitate writing for bilingual learners in "sheltered constructivist" science? *Electronic Journal of Literacy Through Science*, 1. Retrieved January 25, 2002, from <http://sweeneyhall.sjsu.edu/ejlts/merino.htm>
- Rivard, L. P. (1994). A review of writing to learn in science: Implications for practice and research. *Journal of Research in Science Teaching*, 31, 969-983.
- Shepardson, D. P., & Britsch, S. J. (2001). The role of children's journals in elementary school science activities. *Journal of Research in Science Teaching*, 38, 43-69.
- Yore, L. D., Bisanz, G. L., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education*, 25, 689-725.
- Wallace (formerly Keys), C. (2002, April). *An illumination of the roles of hands-on activities, discussion, text reading, and writing in constructing biology knowledge in seventh grade*. Paper presented at the annual meeting for the National Association of Research in Science Teaching, New Orleans, LA.
- Warwick, P. Stephenson, P., & Webster, J. (2003). Developing pupils' written expression of procedural understanding through the use of writing frames in science: findings from a case study approach. *International Journal of Science Education*, 25(2), 173-192.