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ABSTRACT

This study attempted to assess the effectiveness of a science program implemented by two elementary science specialists in a school district in a Western state. The study aimed to compare the potential of elementary classroom teachers and elementary science specialists to implement the reform vision for elementary science education in grades 4-6. The study was exploratory and qualitative in nature. Two science specialists and all 23 elementary classroom teachers for grades 4-6 from the specialists' district participated in the study. It is suggested that elementary science specialists may be more effective than regular classroom teachers in implementing the reform vision for elementary science education. (Contains 24 references.) (ASK)

# An Exploratory Study of the "Effectiveness" of Elementary Science Specialists

by

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# AN EXPLORATORY STUDY OF THE "EFFECTIVENESS" OF ELEMENTARY SCIENCE SPECIALISTS

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The national science education reforms, in their efforts to promote scientific literacy, envision active, hands-on, inquiry-oriented science lessons beginning in the earliest elementary grades (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). Elementary teachers are expected to develop and implement science activities that engage students in science processes and build on students' natural curiosity and common sense knowledge. Such an approach is vastly different from the more traditional, textbook-based approach that many elementary teachers tend to employ (Abell, 1990; Manning, Esler, & Baird, 1981; Stake & Easley, 1978; Weiss, 1978, 1987). In addition, the fact that science instruction is not given priority in elementary classrooms aggravates the difficulty of providing an engaging atmosphere in which science-literacy-related objectives are viewed as important and attainable. Reviews of the status of elementary science reveal that approximately 25% of elementary teachers do not teach science at all, and those who do spend less than two hours a week on the subject. Moreover, these latter teachers tend to emphasize vocabulary and heavily rely on textbooks in their teaching (Abell, 1990; Manning, Esler, & Baird, 1981; Stake & Easley, 1978; Tilgner, 1990; Weiss, 1978, 1987). Thus, the task of implementing an elementary science program consistent with national reforms' recommendations has been challenging, to say the least.

Elementary teachers have voiced several constraints to effective science teaching in elementary classrooms. Among these constraining factors are science content knowledge (Abell

& Roth, 1992; Dickinson, Burns, Hagen, & Locker, 1997; Ramey-Gassert, Shroyer, & Staver, 1996; Tilgner, 1990; Weiss, 1987), lack of time (Stake & Easley, 1978; Tilgner, 1990; Weiss, 1978), inadequate materials and facilities (Abell & Roth, 1992; Helgeson, Blosser, & Howe, 1977; Ramey-Gassert et al., 1996; Weiss, 1987), and other curricular priorities (Dickinson et al., 1997; Hounshell, 1984; Weiss, 1978). In addition to these constraining factors, elementary teachers have attributed their low self-efficacy toward science teaching to the lack of experiences with science, lack of science teaching experience, and perceived lack of achievement ability in science-related topics/areas (Dobey & Schafer, 1984; Perkes, 1975; Ramey-Gassert et al., 1996; Shrigley, 1977; Tilgner, 1990). These constraints, whether real or perceived, gain special significance in the context of national reform efforts (AAAS, 1993; NRC, 1996). Indeed, the ability of elementary teachers to implement the reforms' vision of science teaching has been brought into question.

## A Role for Elementary Science Specialists

In light of elementary teachers' consistent voicing of constraints to teaching science and the growing importance of science literacy, many science educators have suggested that experienced elementary science specialists are more likely to promote science literacy among elementary students than are elementary classroom teachers (Abell, 1990; Hounshell & Swartz, 1987; Neuman, 1981; Williams, 1990). These arguments assert that employing elementary science specialists to teach science in equipped elementary science laboratories would abate the constraints of priority, time, equipment, knowledge, and experience. An elementary science specialist typically holds an undergraduate degree in a science area and additional training in elementary science education. As such, science specialists have substantially more science content and science pedagogy backgrounds than typical elementary teachers do. Because science specialists are only responsible for teaching science in elementary grades and since it is highly likely they are the most knowledgeable and enthusiastic about science in elementary school settings, their primary focus would be developing and implementing science lessons. Many believe that adequate science content knowledge and pedagogy, teaching in separate laboratory settings, and high priority for teaching elementary science enable specialists to deliver *more* innovative and "effective" science instruction relative to what the typical elementary classroom teacher can, or should be expected to, deliver (Abell, 1990; Hounshell & Swartz, 1987; Neuman, 1981; Williams, 1990).

Studies have supported the importance of science content knowledge in using an active, inquiry-oriented approach to science instruction (Dobey & Shafer, 1984). Furthermore, perceived ability to be effective in science teaching has been shown to be associated with factors such as more elaborate science content knowledge (Ramey-Gassert et al., 1996; Shrigley, 1977), successful science teaching experiences (Dickinson et al., 1997; Shrigley, 1977; Tilgner, 1990), and a commitment to more effective elementary science instruction (Ramey-Gassert et al., 1996). These factors have been used to support arguments for a role for elementary science specialists. However, *empirical* research about the effectiveness of elementary science specialists is lacking. Such was the focus of the present study.

## Purpose of the Study

The present study attempted to assess the "effectiveness" of a science program implemented by two elementary science specialists in a school district in a western state. For the purpose of this study, "effectiveness" was measured in terms of achievement of the district's science-teaching objectives for students in grades 4-6. In addition, the study aimed to compare the potential of elementary classroom teachers and elementary science specialists to implement the reforms' vision for elementary science education in grades 4-6. In particular, the present study aimed to answer two questions, (a) What are the differences, if any, between elementary teachers' and elementary science specialists' views of science teaching and instructional planning for grades 4-6? (b) Are elementary science specialists more effective than elementary classroom teachers in helping students achieve "science literacy?" In the present study, "science literacy" was equated with achieving science-teaching objectives for grades 4-6 as outlined in the *National Science Education Standards* (NRC, 1996) and/or *Benchmarks for Science Literacy* (AAAS, 1993).

## Method

The present study was exploratory and qualitative in nature. Much of the data for this study were collected as part of an evaluation project for a participant district's elementary science program. Given the nature of the evaluation process, the investigators did not have direct contact with the participant teachers or students. The investigators had to rely on district administrators for data collection. Nonetheless, frequent communications with the School District Board ensured full access to necessary data and cooperation of district personnel.

### Participants

Two school districts, a "specialists" district and a "comparison" district, in a western state participated in the present study. The districts were comparable in locale and socioeconomic status. Class size for both districts averaged 24 students. The "specialists" district employed two elementary science specialists. All nine 4th grade, seven 5th grade, and seven 6th grade classrooms were taught by the elementary science specialists. All these classrooms, the two science specialists, and all 23 elementary classroom teachers for grades 4-6 from the "specialists" district participated in the study. In the "comparison" district, elementary classroom teachers assumed all science teaching responsibilities. From this district, 12 elementary teachers of grades 4-6, and 17 grade 5 classrooms participated in the study.

A profile of participant teachers from both districts and the science specialists is presented in Table 1. No significant differences were evident between participants in the two districts with respect to gender, age, and years of teaching experience. Both districts had substantially more female teachers than male teachers. The average age for classroom teachers in the "specialists" district was 42 years compared to 44 years for the "comparison" district participant teachers. Science content knowledge background for participant teachers for both districts' was mainly in the biological sciences (approximately 55% of total science course credits were in the biological sciences).

Some differences were evident in the amount and type of undergraduate and graduate science content courses completed by teachers in the two districts. Compared to the classroom teachers in the "specialists" district, excluding the science specialists, the "comparison" district teachers averaged 7 more credits of undergraduate science courses (14 versus 21 credits) and 4 more credits of graduate science courses (6.7 versus 11 credits). Moreover, 50% of the teachers in the "comparison" district had completed at least two graduate courses. In comparison, only 21% of the "specialists" district classroom teachers had completed any graduate course. "Comparison" teacher participants also had more courses in the physical sciences, averaging 9 total credits (undergraduate and graduate) in physical science versus 3 for teachers in the "specialists" district. The other content areas were similar for both districts. Differences were also evident in participation in professional development opportunities. Compared to 66% of teachers in the "comparison" district, only 44% of classroom teachers in the "specialists" district reported having participated in professional development programs or activities.

Table 1.
Profiles of Participant Teachers and Elementary Science Specialists

| Variable | "Specialists" district | | | | | | "Comparison" district | | |
|---|---|---|---|---|---|---|---|---|---|
| | Classroom teachers | | | Science specialists | | | Classroom teachers | | |
| | *n* | *P* | *M* | *n* | *P* | *M* | *n* | *P* | *M* |
| Gender | 23 | 100 | | 2 | 100 | | 12 | 100 | |
| Male | 3 | 13 | | 0 | 0 | | 2 | 17 | |
| Female | 20 | 87 | | 2 | 100 | | 8 | 67 | |
| Age | | | 42 | | | 35 | | | 44 |
| Teaching experience | | | 15 | | | 11 | | | 15 |
| Undergraduate science credits | 20 | 88 | 14 | 2 | 100 | 70 | 11 | 92 | 21 |
| Biological sciences | 17 | 78 | 8.1 | 2 | 100 | 37 | 11 | 92 | 11 |
| Physical sciences | 10 | 44 | 3.4 | 2 | 100 | 18 | 9 | 75 | 7 |
| Agricultural sciences | 2 | 9 | 0.3 | 1 | 50 | 1.5 | 1 | 6 | 0 |
| Geo- and space sciences | 10 | 44 | 2.5 | 2 | 100 | 15 | 5 | 42 | 3 |
| Graduate science credits | 5 | 21 | 6.7 | 2 | 100 | 32 | 6 | 50 | 11 |
| Biological sciences | 4 | 18 | 5.4 | 2 | 100 | 32 | 4 | 33 | 5 |
| Physical sciences | 0 | 0 | 0 | 1 | 50 | 1.5 | 2 | 17 | 2 |
| Agricultural sciences | 0 | 0 | 0 | 1 | 50 | 1.5 | 1 | 8 | 2 |
| Geo- and space sciences | 1 | 6 | 4.5 | 1 | 50 | 1.5 | 3 | 25 | 2 |
| Professional development activities | 10 | 44 | | 2 | 100 | | 8 | 66 | |

Note: *n* is the number of participants who reported data for a particular variable; *P* is the percentage of total participants for the specified district; *M* is the mean of a particular variable for participants in the specified district

The two science specialists differed in terms of teaching experience (2 years versus 19 years) and graduate level science credits completed (17 versus 46). However, both had completed substantially more science credits than participant classroom teachers in either district. The science specialists averaged 102 total undergraduate and graduate science credits, whereas the classroom teachers in the "specialists" and "comparison" districts averaged 21 and 32 total undergraduate and graduate science credits respectively. Like classroom teachers in both districts, the two science specialists had approximately 55% of their total science credits in the biological sciences. In terms of professional development, both science specialists have been active participants in workshops and projects during their tenure.

Context: The Elementary Science Specialists Program

The "specialists" district had established and maintained the elementary science specialists program for 10 years prior to this study. In this district, students in grades 4-6 sit for two 45–55 minute science lessons each week. The lessons are taught by an elementary science specialist in a fully equipped science room. Lessons are intended to be student-centered with facilitation by science specialists and classroom teachers. The science specialist is responsible for lesson preparation, presentation, and grading. Classroom teachers escort students to the science room and are expected to participate as facilitators during lesson delivery. The district describes their elementary science program as comprising four phases. In the first phase, "preparation," the science specialist plans a science lesson that is aligned with the district curriculum goals, organizes the supplies in the science room, and prepares homework sheets and student activities/projects. During the second phase, "initiation," the science specialist introduces the lesson to students. She establishes rules and expectations, assigns students to groups, and gives directions for the activities. In the third phase, "maintenance," the science specialist and the classroom teacher circulate the room to address student questions, monitor progress, challenge students with thought provoking questions, and provide guidance when needed. In addition, they assess student achievement using scoring guides prepared by the science specialist for two sets of objectives per lesson. One set is related to performance or laboratory-skills objectives, and the other is related to content objectives. At the conclusion of the activity, the science specialist presents a closure to the lesson and assigns homework. The fourth phase, "follow-up," takes place in the regular elementary classroom where the classroom teacher makes arrangements for absent students or students with special needs, collects homework, and communicates with the parents about the activities of the science program.

Procedure

Several data sources were used to answer the questions of interest. To minimize potential bias in participant teachers' responses during data collection, every precaution was taken to insure that participants did not perceive the questionnaires they filled and other tasks they were asked to complete as evaluative.

First, all teacher participants in both districts were administered a survey to collect background data and assess their views of science teaching. Participants were asked to respond to four open-ended questions. These questions were:

1. Do you think that teaching science in your classroom is important? Why or why not?
2. What do you think are the most important things to emphasize when you teach science? Why?
3. What, in your view, is the "best" way to teach science to your students? Why?
4. What, in your view, is the best way to assess whether your students learned the science topics, concepts, etc., that you planned to teach them? Why would you use this (or these) assessment strategies?

Second, the science specialists and participant teachers in the "specialists" district were assigned instructional objectives and asked to provide lesson plans that addressed these objectives. Participants were asked to prepare elaborate lesson plans that *detailed* the content, instructional activities, teaching approach, and assessment strategies. The investigators chose the assigned objectives such that these were simultaneously emphasized in the district's elementary science teaching goals and the *Benchmarks* (AAAS, 1993) or the *Standards* (NRC, 1996). Different objectives were assigned to different grade level (4-6). Classroom teachers in each grade level were assigned the respective objective. The two science specialists were asked to write lesson plans for all three grade-levels. The objectives were:

1. Grade 4: Students will be able to analyze, interpret and summarize data from an investigation. In particular, students will be able to realize that just because B follows A does not necessarily mean that A caused B.

2. Grade 5: Students will be able to draw comparisons between three structures that are functionally equivalent in plants and animals.

3. Grade 6: Students will be able to distinguish among chemical, heat and mechanical energy.

Third, the elementary science teaching goals (grades 4-6) of the two participant districts were collected. These two sets of goals were systematically compared with each other and then with the goals specified, for corresponding grade levels, in the *Standards* (NRC, 1996) and *Benchmarks* (AAAS, 1993). This comparison was necessary for two reasons. First, the meaningfulness of any comparison between the two districts was determined by the extent to which the districts' science teaching goals for grades 4-6 overlapped. Second, since achieving "science literacy" in the present study was equated with achieving the science teaching goals specified in national reform documents, it was crucial to establish that the participant districts' elementary science program goals were consistent with those specified in national reform documents (AAAS, 1993; NRC, 1996).

Two types of data were used to determine the "effectiveness" of the science program implemented by the elementary science specialists. First, statewide science achievement test scores for grade 5 students in both districts (197 from the "specialists" district and 327 from the "comparison" district) were compared. Grade 5 students from both participant districts were the only students who took the same standard examination during the spring of 1998, and thus served as the only comparable group for achievement. Second, 40 student work samples from grades 4-6 in the "specialists" district were used to assess the achievement of objectives and/or goals that targeted higher order and critical thinking skills that are not typically measured by statewide standardized tests.

The work samples, or portfolios, were selected by the science specialists to reflect student achievement of cognitive goals with special attention to problem solving and critical thinking. The work samples comprised descriptions of lab activities and student investigations complete with student observations, hypotheses or questions, student-designed investigations, types of data gathered and analyses conducted, and conclusions, summaries, and essays. The two science specialists collected relevant work samples from at least three students in each of the 13 classes they taught during the third trimester of the 1997-1998 school year. They attempted to stratify the sampling based student abilities and achievement.

Data Analysis

Participants' responses to the open-ended science teaching survey were used to generate summaries for participant teachers' views of science teaching. These summaries focused on teachers' views regarding the relative importance of science in the elementary curriculum, science content or concept areas that should be emphasized, effective teaching approaches, and appropriate assessment practices. Participants' responses were examined individually for internal consistency, and then grouped into the appropriate participant category: "specialists" district classroom teachers, science specialists, and "comparison" district classroom teachers. Next, profiles were generated for each participant category. Views of the classroom teachers from both districts were compared and contrasted with those of the science specialists. Finally, views of the classroom teachers and the elementary science specialists were compared to recommendations for elementary science teaching practices and objectives as described in the *Standards* (NRC, 1996) and *Benchmarks* (AAAS, 1993).

The lesson plans prepared by participants were analyzed with a focus on the type of instructional activities used, plans for student involvement, accuracy of science content, and alignment between lesson objectives, instructional activities, and assessment plans. Comparisons were then made between the teachers' instructional plans and their views of science teaching as explicated in their responses to the aforementioned open-ended survey. Comparisons were also made between the instructional planning of classroom teachers and the science specialists.

Multiple linear regression analysis was used to compare the two districts' statewide science achievement scores for grade 5. Student scores served as the response variable while district membership, school membership, and classroom teacher served as explanatory variables. It should be noted that district membership indicated whether students were taught by science specialists ("specialists" district) or elementary teachers ("comparison" district).

Student work samples were examined for type of activities (observation, hands-on, manipulating equipment, inquiry), cognitive skills targeted (knowledge, comprehension, application, problem-solving, and higher order and critical thinking), and evidence for student achievement of target content or skills (adequate/weak). Student achievement was measured by appropriateness and completeness of responses, clarity of thought processes, and demonstrating understanding of the connections between the content and procedures performed. Particular emphasis was placed on student demonstration of problem solving and critical thinking abilities.

## Results

### Views of Science Teaching

The following sections present summaries of participant teachers' views regarding the relative importance of science in the elementary curriculum, science content or concept areas that should be emphasized, effective teaching approaches, and appropriate assessment practices.

#### Importance of Science in the Elementary Classroom.

Based on the responses to the science teaching survey, classroom teachers from both districts and the science specialists held similar views toward science teaching. All participants emphasized that science is important to teach. Several justifications were presented to support this view. As evident in the following quotes, these justifications consistently included viewing science as being relevant to students' lives, and science teaching as necessary for building critical thinking and problem-solving skills and encouraging students' natural curiosity:

> Science requires students to rely on higher level thinking skills as they discover and investigate concepts related to their world. (T 3427)

> Children have a strong interest to learn about the world around them. As an educator, I hope to be able to incorporate this inherent desire to learn into my classroom. I feel a strong background in science is necessary for success in an increasingly global society. (Specialist 2)

A few participants thought that teaching science in elementary grades is important because it helps students achieve other curricular goals such as language arts objectives:

> Concepts in science relate directly to math. Science also connects to reading and writing. (T 0974)

Important Emphases in Elementary Science Content.

The classroom teachers and science specialists were quite similar in emphasizing the "basics" of the different content areas (biological, physical, and earth sciences). Generally, all participants indicated that science instruction should involve problem solving and inquiry-type activities where students are encouraged to explore, experiment, analyze, and make conclusions based on their observations as is evident in the following representative quotes:

> I think the most important thing to emphasize when teaching science is to think. (T 9862)

> Some of the behaviors I emphasize in the science room include: developing a keen awareness, actively pursuing observations and pondering them, looking for correlations, considering evidence, wondering and asking questions, hypothesizing and testing theories, predicting, explaining, and using logic. (Specialist 1)

> [Students need] to become more aware of senses and how to understand what the data from the senses can mean . . . This is problem solving, an organizational tool to train the brain how to evaluate data. (T 6085)

Consistent with their responses to the first question on the survey, participants noted that lessons should emphasize the relevance of science to the students' lives. The majority of participants felt that science instruction should serve to enhance students' interest in science and respect for the natural world. These views explicated by classroom teachers from both districts and the science specialists were generally in agreement with the reform's vision for science education:

> To teach awareness to the students' environment and how they, as individuals, fit into their natural surroundings – and how they can help preserve this for the future years. (T 9436)

> Students need to be introduced to the science around them – nature, trees, plants, oceans and other things they see, feel, experience and take for granted on a daily basis. (T 1613)

The science specialists, however, explicated several *additional* and *important* aspects relevant to elementary science teaching. Both specialists stressed the importance of inquiry in developing problem solving and critical thinking skills. Their views of inquiry were clearly more consistent with current definitions of "scientific inquiry" as explorations comprising many processes and methods to produce reliable knowledge:

> Science is a process for producing knowledge. The process depends both on making careful observations of phenomena and on inventing theories for making sense out of those observations. (Specialist 2)

> [Inquiry] enables students to ask questions and then develop experiments or research to answer the question in their own terms. (Specialist 1)

Contrary to the view held by the science specialists, 25% of the classroom teachers from the "specialists" district and 50% of the classroom teachers from the "comparison" district explicitly stressed the use of "The Scientific Method" as a single algorithm for "doing science" and solving problems:

> The Scientific Method and describing the steps involved is most useful. This helps the student to inquire about nature; follow an orderly, controlled approach to solving a problem. (T 8365)

> I think it is important to emphasize the scientific method. Students need to learn how to form a hypothesis and design an experiment to discover whether their hypothesis is correct. (T 2865)

Furthermore, in contrast to classroom teachers and consistent with the reform documents' emphases (AAAS, 1993; NRC, 1996), the science specialists identified specific aspects of the nature of science they felt are important to emphasize when teaching science. For example, Specialist #1 emphasized the importance of teaching students about the tentative nature of science. She noted that "providing students with the opportunity to explore their own misconceptions and to construct their own understanding of concepts will allow students to realize that scientific ideas are subject to change." She also stressed the importance of teaching the empirical and creative nature of science. The second science specialist emphasized the importance of cooperation, sharing of ideas, and the tentativeness of scientific knowledge.

<u>Approaches to Science Teaching.</u>

Participants' views were similar regarding the most adequate approach to teach science. Eighty-five percent of all the teacher participants believed that an active, "hands-on" approach that emphasized relevance of science to students' lives was the "best" approach to teach science. Such an approach was intended to allow students to develop and answer their own questions. One classroom teacher stated, "Let the kids manipulate science materials and problem solve using open-ended questions."

However, the science specialists differed in detailing a teaching approach that was more aligned with a "constructivist" view. They also stressed the importance of integrating the different subject areas. Both science specialists also expressed the need to provide students with several opportunities to explore, synthesize and make connections between concepts in various contexts:

> I feel that science should be taught by way of an inquiry or constructivist approach . . . [that] . . . emphasizes the use of concrete, hands-on experiences; draws upon multiple learning contexts from a variety of disciplines and settings; and maximizes the students' use of the concept in language, both written and oral. In this student centered teaching model, independent activities are designed to support the concepts being taught while students are responsible for constructing their own understanding of the concepts. (Specialist 2)

By detailing specific lesson examples in their responses to the survey, they both indicated that such extended lessons may span several weeks or even a whole term, and allow integrating other disciplines and skills such as mathematics, history, writing, and oral communication.

Assessment Strategies.

In regard to assessment practices, classroom teachers from both districts were quite similar in their responses. In general, they viewed the use of various assessment techniques, both traditional and alternative, as necessary for gaining a sense of student achievement. The most recommended assessment method was student projects coupled with oral presentations. The majority of classroom teachers believed that formal and informal discussions are also important for "accurate" assessment. Of equal status with discussions, based on frequency of responses, was the use of recall tests. The precise nature of such tests was not elucidated by any of the respondent teachers, but the frequent use of the term "recall" indicated that such exams would target assessment of student knowledge of specific content and vocabulary. Next in importance, again based on frequency of responses, were laboratory reports and worksheets when used as summative assessment methods. Finally, a few (15% of the participant teachers) indicated they would also include guided reflections, creative writings, and standardized tests in their assessment practices. Overall, the classroom teachers focussed on summative assessment techniques.

The two science specialists also stressed the use of a variety of assessment methods, although more emphasis was placed on formative assessments. Specifically, they detailed means to assess psychomotor skills, cooperative learning skills, and "thinking skills" primarily by observations, and questions and discussions with students during the class periods. The specialists noted that they use laboratory journals with writings and reflections to assess the affective objectives of the science program. Summative assessments included laboratory activity worksheets requiring summaries of student work, conclusions, and answers to open-ended questions.

Additionally, the two specialists stressed the relevance of student term projects and outlined the assessment guidelines of such projects. For example, students are required to conduct an investigation of their choosing and give an oral presentation to their peers. The presentation is videotaped and reviewed by the presenter and the teacher for feedback and reflection. Written reports are scored according to content, organization, grammar, and use of resources.

Constraints to Teaching Elementary Science.

Even though the teacher participants were not asked to explicate their concerns about their individual abilities to teach science, many teachers from the "specialists" district stated several constraints to teaching science at their grade level in their individual classes. Among these constraints were lack of time, content knowledge, experience, and equipment and space:

> Hands on activities are by far the best way to teach science to students . . . Unfortunately, in a regular classroom, it is more difficult to offer as many of these kinds of activities due to restraints such as preparation time, lack of materials and space. (T 3982)

> There is not enough time to prepare hands-on activities for the regular classroom teacher. Also, I do not have the vast scientific knowledge to draw upon. (T 1375)

Additionally, 16 of the 23 participant teachers from the "specialists" district indicated the need for the science specialists to effectively teach science to their elementary students. Again, it should be noted that the teachers were responding to the aforementioned survey questions and were not prompted in any way to express their views about their *abilities* to teach science or their views of the science specialists:

> Having a science specialist is a great help because it takes time to prepare a lab and gather the materials for it. The specialist has more time to do this than a classroom teacher that is preparing for many other subjects. The science specialist also has time to research information so they have more specific knowledge about the topic areas. (T 2865)

> The best approach is to have a person who is trained and interested in science. Most teachers are not qualified to teach all areas of science (and 7 other subjects at least) in their classroom to the degree that the trained science teacher is. (T 1677)

> Hand on activities are best. Having a science specialist is most beneficial because that person has the time, the place and the materials to do a more thorough job than the classroom teacher. (T 6464)

These constraints to teaching science in elementary classrooms are not different from those documented in the literature. However, teachers' beliefs regarding the significance of these constraints might have been aggravated by having observed and helped science specialists teach well-planned and involved science lessons. This might explain why many classroom teachers from the "specialists" district, and none from the "comparison" district, felt they needed to articulate the aforementioned constraints (whether real or perceived) to teaching science even though they were not prompted to do so.

Instructional Planning

In general, the "specialists" district elementary classroom teachers' instructional plans were not congruent with their views of science teaching. Many plans were heavily textbook-based, and involved activities in which students copied and/or labeled various diagrams. This finding is consistent with previous research on textbook use (Stake & Easley, 1978; Weiss, 1978, 1987). This was especially apparent in the case of most grade-5 lesson plans that required students to look at diagrams of cell types and label their components. Furthermore, much of the "hands-on" activities were little more than students "handling" different materials during a single class period.

The activities planned by classroom teachers were loosely linked to the assigned objectives and lacked a "minds-on" or reflective components. Activities were primarily demonstrations of specific content requiring very little by way of problem solving or critical thinking. Assessments mainly comprised worksheets for vocabulary, observations, and lower level comprehension questions, and written summaries of the activity. These lessons were not consistent with the teachers' aforementioned views of what and how science should be taught in their classrooms, nor were they consistent with the reform recommendations for elementary science teaching. In addition, some of the elementary teachers' plans included inaccurate science content. Only 4 out of the 23 classroom teachers (17%) provided adequate details and appropriate lessons for the objective they were assigned.

By comparison, the specialists used a variety of hands-on activities, purposefully and accurately designed to achieve the specified objectives. Their lessons included inquiry-based activities where students were required to develop hypotheses, design and conduct investigations, and analyze their observations in relation to their predictions. Specialists' lessons spanned several class periods and encouraged students to establish connections between several ideas. Assessment plans included worksheets, open-ended discussions, and written and oral summaries of lessons where students draw conclusions from several activities and make generalizations. As such, the science specialists' instructional planning, when compared with the planning of the classroom teachers, was more consistent with their views of science teaching and with the national reforms' recommendations for elementary science education.

"Effectiveness" of the Elementary Science Specialists

The "effectiveness" of elementary science specialists was defined in terms of achieving the "specialists" district elementary science program goals relative to what could be achieved by regular classroom teachers. To shed light on this relative effectiveness, statewide science tests scores for students in the "specialists" and "comparison" district were compared. To insure the meaningfulness of this comparison, the elementary science program teaching goals in the two districts were analyzed for overlap. Moreover, the potential of elementary science specialists to help students achieve "science literacy" was defined in terms of achieving science teaching goals specified in national reform documents (AAAS, 1993; NRC, 1996). As such, the two districts' elementary science program goals were compared with goals specified in these latter national documents for corresponding grade levels.

Comparison of Goals of the Elementary Science Programs.

The contrast focussed on the content of the goals for the two districts, their scope, and their appropriateness for the specified grade levels. In general, there was substantial overlap between the two districts' goals.

Of the "specialists" district's listed goals, at least 90% were in agreement with the *Standards* (NRC, 1996) and/or *Benchmarks* (AAAS, 1993) for each grade level. For grade 4, the "comparison" district submitted only two science goals. Both goals were related to understanding aspects of scientific inquiry. Thus, the percent match between the two districts' science goals for grade 4 was only 9%. However, according to the *Standards,* these common goals that targeted scientific inquiry are appropriate and important for grade 4 students. For grade 5, there was 74% agreement between the two districts' goals, with 96% agreement between the "specialists" district's goals and the *Standards*. Finally, for grade 6, there was 50% overlap in goals for both districts, with the "specialists" district having a 90% match with the *Standards* and/or *Benchmarks*.

The above level of overlap between the two districts' goals substantiated the meaningfulness of the comparison of student achievement of science goals in the "specialists" and "comparison" districts. Goals common to both districts and at least one of the national documents were used for comparing student achievement in the two districts.

Analysis of Statewide Test Scores.

Scores for the state's 1998 statewide science test for 5th grade students in the two districts were compared by multiple linear regression. A summary of the analyses is presented in Table 2. Student scores (total scores as well as individual skill area scores) served as response variables while district membership, school membership, and classroom teacher served as explanatory variables.

It was determined that class size, although variable from 11 to 29 students, was not significantly associated with the student achievement scores ($p > 0.05$). Moreover, no significant differences ($p > 0.05$) were evident between total science scores on the science achievement assessment, inquiry, earth science, and unifying concepts for students in the two districts. However, there were two areas where student scores differed significantly according to district membership. These areas were life science ($p < 0.01$) and physical science ($p < 0.001$). Compared to the 5th grade student participants in the "specialists" district, 5th grade students in the "comparison" district tended to score on the average 3 points higher in the life science assessment and 8.5 points higher in the physical science assessment. However, the *practical* significance of this difference is minimal given that scores on these assessments averaged around 520 points. Thus, a difference of 3 or 8 points out of 520, although statistically significant, is of no practical importance. As such, 5th graders in the two districts did not differ in their achievement as measured by statewide science assessments. In this regard, the elementary science specialists were not more "effective" than the elementary teachers in achieving those science program assessed by statewide science tests.

It should be noted that for total, inquiry, earth science, and physical science scores, there were significant differences according to the particular school ($p < 0.05$) as well as the particular

Table 2.
Summary of Multiple Linear Regression Analysis:
5th Grade Scores on the 1998 State Science Assessment.

| Response variable | Explanatory variables[1] | Coefficient | Two-sided *p*-value |
|---|---|---|---|
| Total | District | -2.8888 | 0.0536 |
| | School | 2.3058 | 0.0189* |
| | Teacher | -0.7961 | 0.0242* |
| Unifying | District | -0.5414 | 0.6116 |
| Life science | District | -3.0190 | 0.0052* |
| Physical science | District | -8.4129 | 0.0001* |
| | School | 4.8652 | 0.0007* |
| | Teacher | -1.4319 | 0.0053* |
| Inquiry | District | -1.0948 | 0.5800 |
| | School | 2.5721 | 0.0473* |
| | Teacher | -0.9734 | 0.0368* |
| Earth science | District | -2.9361 | 0.2059 |
| | School | 3.2820 | 0.0313* |
| | Teacher | -1.2187 | 0.0263* |

[1]For the "District" variable, student scores from the "comparison" district were used as the reference. Thus, the coefficient value represents the estimated difference in scores obtained by the "specialists" students relative to the "comparison" students.
* $p < 0.05$

teacher ($p < 0.05$). Again the *practical* significance of these differences (1 to 5 points) was minimal.

It should also be noted that these results were based on a single performance of 5th grade students from the two districts on the statewide science assessment. As previously explicated, these were the only comparable data available at the time the study was conducted. Nonetheless, the results indicate that 5th graders in the "specialists" district did not achieve better than students taught by regular classroom teachers on standardized tests. However, standardized tests typically measure student achievement of knowledge and comprehension level objectives.

Analysis of Student Work Samples.

Student work samples contained various laboratory activity worksheets, summaries, and reflections from the third term of the school year. Each student folder contained work related to 10–18 different activities. Examination of student work samples indicated that the science-related experiences provided to students in grades 4-6 in the "specialists" district were consistent with the instructional plans written by the science specialists. Students were provided multiple opportunities to engage in inquiry-based activities. Many of these activities required students to design a method to address a given problem or question, conduct the investigation, and analyze the results relative to the initial question or problem.

When analyzing these work samples student demonstration of the use of some systematic approach to an investigation, rather than random trial and error, was considered evidence of problem solving ability. Demonstration of consideration of relevant evidence and variables to reach a conclusion was considered evidence of critical thinking ability. In addition, accurate responses to analysis, application, synthesis, and evaluation questions were weighed as evidence for higher order thinking skills.

Analysis of student work samples indicated that, in general, students taught by the science specialists demonstrated adequate understandings of science content and processes, and made relevant connections between content, concepts, and relevant applications. In addition, students demonstrated achievement of higher level cognitive objectives including problem solving and critical thinking. Additionally, students were fairly successful in demonstrating skills of science-based inquiry. Specific achievements of the three grade levels varied somewhat and are described below.

*Grade-4 Work Sample Analysis.*

Fourteen samples from grade 4 were provided. All 14 students demonstrated adequate knowledge and comprehension of most of the activities. They all demonstrated skills in use of a hand lens, measurement devices such as scales and rulers, and graphing techniques. Most of the included activities required students to make and keep record of observations. For example, students examined various types of feathers. From their observations, students were asked to make some inferences as to the functions of the different types of feathers. This activity related structure and function, a goal common to the *Standards* recommendations for 4$^{th}$ grade science.

The 4$^{th}$ grade students were provided opportunities to develop and demonstrate achievement of problem solving and critical thinking skills while participating in relevant and on-going investigations. More than half of the students in the sample demonstrated problem solving skills and critical thinking abilities. For example, in an activity involving the motion of a pendulum, students were asked, "How is the height of a swinging mass related to its energy?" The students were asked to provide an initial hypothesis and then investigate how changing the initial height of the pendulum relates to the distance a wooded block is moved when hit by the pendulum. After collecting data, the students were asked to explain what they learned. One student adequately noted, "I learned that the higher the swing mass is the more energy goes up. The higher the swing, the more work is done." (Tyanna).

Students performed a three-week project where they compared the growth rate of a bean and a corn seedling. This project required students to make observations over the three-week period, measure plant height, graph their results, and interpret the graph to determine the relative rate of growth of the two seedlings. They were then required to prepare a written summary of their project. In general, the students consistently made appropriate observations, demonstrated measurement and graphing skills, and drew appropriate conclusions from their results. Most students demonstrated accurate understandings of their results. They were able to describe their observations and compare the bean and corn seedling growth rates.

> My bean was smaller than my corn plant on the first week. On the second week my bean plant sped ahead at 13 centimeters and my corn only at 9 centimeters. The corn plant didn't grow half as fast as the bean plant. The corn plant sticks straight up and the bean seems to pop its head out. The bean plant has wavy veins while the corn sticks straight up. There's a purplish [color] at the bottom of the stem [and] the bean plant is mostly green. (David)

Students were also given opportunities to reflect on the activities in which they were engaged. When asked what the most interesting part of the corn/bean investigation was, most students responded favorably towards measuring the plants over time and then being able to determine that one grows faster than the other. To these students, the activity was fun, relevant, and an exercise in data collection and analysis.

*Grade-5 Work Sample Analysis.*

Eight samples from grade 5 were provided. All eight students demonstrated knowledge and comprehension of most of the activities in the folders. Their folders also indicated that these students had practice in using hand lenses, microscopes, measurement devices such as scales and rulers, and graphing techniques. All were able to make applications of concepts and analyze results, at least, in some of the activities. Most students consistently demonstrated adequate observation, description, and comparison abilities as they were provided many opportunities to engage these skills.

Of the eight students, only three demonstrated consistent problem solving and/or critical thinking abilities. The other five were inconsistent in applying problem solving and critical thinking. They were often unable to make connections between observations and inferences based on the questions of interest. In addition, they did not always carry out adequate analyses of data or reach relevant conclusions. For example, in an investigation of the effects of water temperature on respiration rate in fish, the students were asked to make a prediction as to how they think the water temperature affects the number of gill beats of the fish. Students conducted the experiment by counting gill beats of a fish in warm and cool water. The variety of student responses revealed that not all students were able to relate the data to their original hypothesis or even the topic of interest. One students noted that, "The average of the temp. when it was cold is 40. The average of the temp. when it was warm is 129. The highest cold temp. is 42. The highest warm temp is 150" (Russ).

The responses of a few students demonstrated an understanding of the experiment and some critical thinking skills. These students related the collected data to their original hypothesis in order to draw appropriate conclusions. For example, Julia noted that, "At 19 degrees my average beats per minute was 61. Then, at 28 degrees, the average beats per minute was 103. That raised 49. My hypothesis was right, when it got warmer the beats were faster."

Fifth grade students participated in several inquiry-based investigations. One such activity required students to design a container that "would hold as much heat energy as possible." Students were asked to describe their design, test it, and then describe how well it worked. They were to compare their designs and results with others in the class, and then suggest reasons for why their design worked well or not-so-well and suggest ways to improve it. Reports from this inquiry-based exercise indicated that most students (more than two thirds) were successful in demonstrating some inquiry-related skills such as design, testing, and making appropriate generalizations based on collected evidence. One student, Jennifer, reported her design and results to demonstrate problem solving, critical thinking, and inquiry-based skills involved in the investigation:

> This is the way we built our container. First we took one foam cup and tore the top part of the cup off. Then we took our other two whole cups and put one inside another. Next we took the bottom part of the cup and put it upside down in the two whole cups. Then we took our top part and stuffed it between the two whole cups and the one bottom . . .Our cup worked better because we had double insulation and it didn't have as much room to travel in. We could have improved it by pushing our top down more. (Jennifer)

In general, grade 5 students demonstrated some problem-solving and critical thinking abilities, although somewhat inconsistently. Similar to the 4th grade sample, students in the 5th grade sample were provided opportunities to develop problem-solving and critical thinking skills while participating in relevant and on-going investigations.

*Grade-6 Work Sample Analysis.*

Eighteen samples from grade 6 students were provided. All folders from the 6th graders contained a variety of inquiry-based activities that involved making observations, descriptions and predictions, collecting, analyzing, and synthesizing data, and applying the target concepts. One such activity required students to predict how temperature affects germination of radish seeds. They were to state a hypothesis, follow the general procedure given to them to collect relevant data, and then state their conclusions. They were not given any guiding questions to prompt them to relate their observations to their stated hypothesis. Thus, those students who drew appropriate conclusions from their data were considered to demonstrate critical thinking. Students were also asked to apply what they had learned to other plants in different climates. The analyzed work samples showed that a few students were able to infer meaning from relevant evidence, and then apply their knowledge to plant survival in different climate conditions:

> Hypothesis: I think that the seeds in the warmer temperature will grow and the others will die. This is because seeds need lots of sunlight and water and the right temperature to start growing.

| | | | |
|---|---|---|---|
| Data: | Warm area: | # of seeds germinated: 10 | Total seeds: 10 |
| | Cold area: | # of seeds germinated: 1 | Total seeds: 10 |

> Conclusions: The warm seeds grew better than the cold seeds, I found. Actually much better. About 97% of the warm seeds grew, but only about 22% of the cold seeds grew. So my hypothesis was right. The warm seeds grew better than the cold seeds.

> How would a change in climate select certain plants? If there was a loss of temperature it would probably kill the warm climate plants. If the temperature rose the cold climate plants would die. If tit began to rain, the desert plants would die. If it dried out, the rain forest plants would die. (Brian)

Controlling variables was common to many of the activities. For example, one activity involved the study of the concentration of borax on the texture of the final "GAK" product. The stated purpose of this activity was "to conduct a controlled experiment using one variable." One student, Andy, concluded that:

> The more borax solution you put in, the rougher the texture and the chunkier the gak is. I thought that the more borax you put into the mix the rougher the texture was. That was right. [Sample] M had 12 ml of borax solution, which was the most, and it had the roughest texture. Versus [sample] A which was "pourable" and looked like milk.

Some students suggested investigations to further explore their questions that arose from doing the investigations:

> As the concentration got higher the velocity [viscosity] also got higher. [Sample] A was liquid because it had less borax solution, and M was really hard because it had a lot of borax solution . . . One question I came with while working on it was, Would it affect the result of the gak by using salt water? (Delores)

Another activity required students to design an investigation to determine the relative densities of several liquids. The students then performed their proposed designs, analyzed their data, stated their conclusions, and reflected on the appropriateness of their procedure. The sample presented here demonstrates a logical thought process before and during the investigation to solve the target problem:

> Problem (given): Find which liquid is the most dense. Find the least dense liquid. Fill the small test tube with all four liquids stacked in colored layers, with the most dense liquid on the bottom.
>
> Strategy (Explain how you will solve the problem): We will mix 2 colors and find out which of the 2 is more dence [dense]. We will do it again with the other colors. Then we will test the dencer ones and find the more dence one and then we will do the same with the least dence. Last we'll stack 'em.
>
> Notes: We put red on the bottom first and then we put yellow on the top. They mixed so we put yellow on the bottom and they didn't mix. So red was more dence. Next we did green and blue with green on the bottom and blue on the top. They mixed, so we tried again and blue was more dence. Then we mixed yellow and blue, yellow was more dence. Then we knew that yellow was most dence. Blue was next. Red was second to least and green was the least dence.
>
> Conclusion: The most dence color was yellow and the least dence color was green. [She included a picture of the final test tube with the stacked liquids.] (Katie)

These types of activities indicated that the students were provided many opportunities to develop inquiry-related skills. In regard to these activities, the larger majority of these 6th graders demonstrated adequate knowledge and comprehension of the science content and concepts. More than two thirds of them demonstrated competent problem solving abilities, and critical thinking skills.

Several students demonstrated proficiency in synthesizing several ideas in order to answer another question. For example, students were given information about the tide levels at various times during several months. They were also studying the phases of the moon. Students were asked to relate the level of the tides with the positions of the moon. In addition, they were required to incorporate the effect of the gravitational pull from the moon and sun. Of the eight portfolios that contained this activity, six demonstrated understanding of the relationships. Four of these were able to suitably represent their ideas with both diagrams and written descriptions.

Summary of Analysis of Student Work Samples.

Analysis of student work samples indicated that the majority of students taught by the science specialists demonstrated understanding of science content and processes as evident in their problem-solving centered investigations and abilities to make inferences and connections from several activities. The instructional planning of the science specialists and apparent student achievement of higher order objectives revealed that the science specialists were successful in implementing their views of science teaching. They also demonstrated their ability to help students achieve science instruction goals congruent with those called for in national reform documents.

## Conclusions

This study lends some empirical support to the suggestion that elementary science specialists may be more effective than regular classroom teachers in implementing the reforms' vision for elementary science education. The elementary classroom teachers in both districts expressed views of science teaching that were similar to those of the science specialists' views. The views of the science specialists, however, were more consistent with current views of "effective" elementary science instruction. Moreover, unlike the science specialists, the instructional plans of the classroom teachers were not congruent with their stated views of science teaching. In general, the elementary classroom teachers' planned lessons included few student-centered activities with minimal opportunities for student inquiry or enhancement of higher level cognitive objectives. In contrast, the lesson plans of the science specialists, as well as evidence for their planning included in the student portfolios, indicated that students taught by the science specialists were engaged in multiple activities, aimed to integrate several concepts and *engage* students in constructing meaning.

Analysis of science achievement for students taught by the classroom teachers versus students taught by science specialists indicated that students in grade 5 did not differ in achievement as measured by the statewide science assessment. However, analysis of other student data demonstrated that students in grades 4–6 taught by the science specialists did demonstrate higher order cognitive skills such as problem solving and critical thinking. In addition, as previously stated, the science specialists planned and implemented lessons appropriate for enhancing these skills. They used a variety of teaching approaches and encouraged students to make applications of the science content in the classroom to every day situations.

Even though more research is in order, the results of the present study seem to indicate that the *likelihood* was minimal for the classroom teachers in the "specialists" district to implement as effective an elementary science program as that implemented by the science specialists. The instructional planning of the classroom teachers suggested they were more likely to deliver teacher-centered, textbook-driven science lessons that targeted acquisition of knowledge and comprehension level instructional objectives. Classroom teacher plans did not articulate activities that would involve students in open-ended investigations that aim to help them develop higher order and critical thinking skills.

The quality and emphases of classroom teachers' planning (and possibly teaching practices) could be attributed, at least in part, to their limited content knowledge. This inference is supported by the fact that the elementary science specialists and classroom teachers in the specialists' district differed mainly in their science content knowledge. This inference is also consistent with previous research relating subject matter knowledge and teaching approach. (Dobey & Shafer, 1984; Hashweh, 1987; Hollon, Roth & Anderson, 1991). The science specialists' elaborate science content knowledge and science teaching experience may account for their success in implementing a science program that targets higher order objectives, and encourages inquiry, problem solving, and understanding of the nature of the subject (Hollon, Roth & Anderson, 1991; Lederman, 1992).

The apparent absence, in the case of the science specialists, of many of the constraints for teaching science in elementary classes often voiced by classroom teachers, coupled with evidence that supports the effectiveness of the specialists' program suggests that there may be a significant role for elementary science specialists in promoting "science literacy" among elementary students. However, the cost of supporting such a science program may be unrealistic for many school districts (Rhoton, Field, & Prather, 1992). Using science specialists solely as subject matter teachers may prove to be cost-ineffective. Several models for the use of elementary science specialists have been described that involve the specialists in a variety of roles (Abell, 1990). For instance, science specialists could play an active role in the professional development of elementary teachers. In the case of the present study, however, the science specialists assumed all responsibility for science teaching to the demise of their role in professional development. Furthermore, critics of the role of elementary science specialists suggest that such exclusive use of specialists in science teaching makes science more elite and impersonal (Hounshell & Swartz, 1987). Further investigation into these concerns is needed in order to develop a more complete understanding of the potential benefits that science specialists could bring into elementary science teaching. The present study provides evidence of the apparent benefits toward student achievement of "science literacy."

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