The Development of Middle School Students' Inquiry Strategies in Project-Based Science Classrooms

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Inquiry is an essential component of science learning (Lunetta, in press; Roth, 1995). New constructivist and social constructivist approaches to science instruction feature inquiry as essential for student learning. These approaches assume that students need opportunities to find solutions to real questions by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings. A number of programs have been developed that stress engaging students in inquiry. Examples include Scientists in Action developed by the Cognition and Technology Group at Vanderbilt (1992), Linn's (in press) Computers as Learning Partner, Songer's (1993) Kids as Global Scientists, Brown and Campione's (1994) Community of Learners, and Peas' (1992) Collaborative Visualization.

Although evidence indicates that students obtain deeper understanding using these approaches (e.g. Brown & Campione, 1994; Cognition and Technology Group at Vanderbilt, 1992), there are few extensive descriptions of how students engage in inquiry and how their engagement changes with experience (for exceptions, see Roth, 1995, and Schauble et al., 1995). Moreover, many of the instructional studies have been conducted in highly supported demonstration sites (Linn, in press) or in classes taught by the researchers (Roth, 1995). Although useful for establishing the benefits of inquiry learning, such studies are limited tests of the potential that inquiry might have in the rough and tumble realities of regular classrooms.

Our previous work describes the challenges of instantiating inquiry in science classrooms and supporting students' efforts (Blumenfeld et al., 1994; Marx et al., 1994). Other researchers identify problems with students' thoughtfulness, e.g. students are not systematic when engaging in inquiry activities (Scardamalia & Bereiter, 1991). Similarly, Palincsar, Anderson, and David (1993) suggest that students have difficulty engaging in thoughtful conversations in which they systematically discuss ideas or consider evidence.

This study helps fill the void in the empirical research on students' long term experiences with inquiry. We describe how students engage in inquiry and how it changes over time. We focus on how students ask questions, plan designs and procedures, conduct investigations and make observations, and interpret data and draw conclusions.

Methods

Setting

The study was conducted in 2 seventh grade science classrooms (n of 18 and 24) taught by 2 teachers in an independent school in a small urban community. One teacher has taught for five years; she has a BS in secondary science education with a major in broadfield natural science and a minor in biology and a MS in child development. The other has taught for 21 years and has a BS with a major in biology and a minor in chemistry, secondary school teaching credentials and a MS in biology. The teachers worked together to plan and implement inquiry teaching.

The teachers use a form of inquiry instruction called project-based science (PBS). PBS is one of several attempts to instantiate constructivist theory in classrooms (Blumenfeld, et. al, 1994). The features include: a) a driving question, encompassing worthwhile content that is meaningful and anchored in a real-world problem; b) investigations and artifacts that allow students to learn concepts, apply information, and represent knowledge; c) collaboration among students, teachers, and others in the community; and d) use of technological tools. Both teachers volunteered to attend PBS institutes during the summer and continued to attend worksessions during the school year. However, their classrooms should not be considered demonstration sites; they received no extra money or equipment and did not have extra classroom help.

Data Collection and Analysis

We used intensive observations and interviews with target students to describe their inquiry. We also collected student artifacts including assignments, notebooks, tests, and reports. In each class, teachers nominated 4 students

(2 boys and 2 girls) for intensive observation. The teachers judged that all were in the middle range of science achievement for that classroom, did not have serious classroom adjustment problems, and were talkative enough to be informative interviewees. Each class was videotaped about 3 or more times weekly. Observations were conducted primarily during times when students were involved in investigations, creating artifacts, and presenting their work. Students often worked with others in collaborative groups. The composition of collaborative groups changed often either through self-selection or by teacher selection. We interviewed target students generally every other week to discuss inquiry activities.

We developed a case study for each student depicting their engagement in inquiry during three projects (for brevity, this paper is based of four--2 girls and 2 boys--representative students). The analysis scheme focuses on aspects of inquiry and the quality of their engagement. We divided inquiry into four broad areas: a) developing questions; b) planning procedures and designing investigations; c) conducting investigations and making observations; and d) analyzing data, drawing conclusions, and providing explanations.

Quality assessments in the first area addressed asking questions, making predictions, gathering information, and considering alternatives. The second area included generating designs such as controlling variables and having a variety of data sources, and devising procedures such as gathering materials and creating ways to measure and represent the data . The third area included constructing apparatus, following procedures, and the completeness and precision of qualitative and quantitative observations. The last category examined the accuracy of data interpretation, conclusions drawn, and explanations offered.

Projects: Opportunities for inquiry

Over the seven month data collection period, the students participated in three projects, summarized below. We present the driving questions, opportunities for inquiry, and possible artifacts, along with descriptions of how teachers supported inquiry. The first project was meant to serve as a transition to PBS; as such the inquiry was more tightly structured and constrained in terms of the questions, procedures and complexity, than in subsequent projects.

Project 1: How can you tell what a substance is if it has lost its label?

This project occurred during October and November. The entire class explored the same question--"How can you tell what a substance is if it has lost its label?" The main investigation was adapted from the often used "Mystery Powders" activity. In answering this driving question students explored fundamental ideas in chemistry such as physical and chemical properties, identifying substances, states of matter, and atomic and molecular structures and formulas. Student pairs were given different white powders and asked to identify the 3 substances. They made observations, took notes, interpreted findings, and drew conclusions. Students wrote a report describing the reasons for their conclusions and made a brief class presentation.

The teachers used this project to introduce students to inquiry. They structured the task to scaffold inquiry. Before students were given their mystery powders, teachers provided students with experience conducting tests to identify different substances. Teachers also introduced students to the chemical composition and physical characteristics of the substances. Teachers also required students to plan how they would identify the unknown substances in their powder. Students needed to decide the tests to perform, select necessary materials, sequence the tests in order to determine the substances by eliminating some possibilities and identifying others. The teachers wanted students to learn to conduct and record their observations carefully and completely. Therefore, they also made suggestions that in their notebooks students include what they did and what they observed, interpret what the observation meant, and describe their next steps and the reasons for them.

Project 2: "Where does all our garbage go?"

This project occurred from January to April. In answering the driving question students explored the following scientific ideas: decomposition; recycling; renewable and nonrenewable resources; and the influence of humans on the environment. The main investigation involved exploring what materials will and will not decompose. Students generated their own sub-question and made predictions about how a factor they chose, like moisture, air or light, would influence decomposition. Students then planned an experiment and created a decomposition environment to answer their question. Students also planned how to make and record observations over a three week period. A number of artifacts were generated including research journals, class presentations of initial experimental design and plans for creating a decomposition environment, classroom presentation about findings, and a decomposition booklet describing their work.

During this project, teachers released more responsibility for inquiry to the students. In contrast to the previous project, students generated sub-questions, plans, and formats for recording observations. Data collection occurred over a longer period than in the previous work. However, the teachers still provided some structure. The class discussed issues related to decomposition and was given materials that provided ideas on how to create a decomposition environment. Students presented their initial questions and plans and received feedback from the class and teachers.

Project 3: "Water, water everywhere! Is there enough to drink?"

This project occurred from late February to April. Students explored scientific ideas such as the water cycle, watersheds, pollution, water quality tests, and concentration. The main investigation involved student pairs generating their own question regarding some aspect of water or its uses, such as "How can I tell if the water is clean?" Students designed and conducted an investigation to answer their question and then created a report. In addition, they made presentations to the class.

During the project, teachers released even more responsibility for inquiry to the students. The range of possible questions and designs was more extensive than in the previous projects. Students were given more leeway in designing the content, format and type of media to be used in their reports. However, the teachers still provided support. For instance, the class discussed questions in terms of feasibility and worthwhileness. After students created a plan for answering the question they received feedback again from the class and from the teacher.

Results

First we present the major findings organized by the four areas of inquiry described above. We illustrate each of the findings with examples drawn from the case studies of four students (Krajcik, et al., 1996). We then present one abbreviated case study to characterize changes in the use of the student's inquiry strategies.

Asking Questions

Students' questions were often based on their personal interests or knowledge of a scientific procedure rather than curiosity about scientific phenomena. As students progressed in their inquiry experiences through the year, their questions became more feasible; that is, they were able to find answers based on their prior knowledge and emerging understandings, the physical resources available to them, and the time to do their research. For some of the students, their questions also became more worthwhile in that the questions created more opportunities to learn pertinent subject matter and conduct investigations. It was not until the water project that some students began to refine their questions. These changes in questions were prompted by support from their teachers. Overall, by the end of the year, most students' questions remained at a descriptive level rather than becoming relational. However, some students, prompted by the teacher, began to ask more relational questions.

For example, in the water project, Alice and her partner developed their question, "Does water in various sites have fecal coliform? If so, to what degree?" The partner proposed that they test for the presence of fecal coliform in different water samples using a kit that he had used to test the water quality in his pond. Initially they did not appear to understand the implications of having too much fecal coliform, and were just excited by the possibility of using the water kit. Importantly, the students' question stemmed from knowing how and wanting to perform a scientific test rather than interest in the phenomenon. However, with encouragement and support from their teacher, the students gathered and analyzed background information on the topic. Through these efforts, students were able to provide an explanation for why the question was worthwhile. Their question was also feasible in that they could design an investigation to answer it.

In the earlier decomposition project, Alice's group posed a question, "What is the effect of acid rain on decomposition," because they wanted to compare the effect of apple juice and water on decomposition. The group picked this question because they liked apple juice. The students considered apple juice as a representation of acid rain because the pH reading of apple juice was comparable to that of acid rain according to a source they read, even though the additional ingredients in apple juice rendered it inadequate as a proxy for acid rain.

In both examples, the students' questions were not based on curiosity about scientific phenomena, but rather resulted from convenience. In the earlier project, even with support of their teacher, they were unable to construct a question that lead to the exploration of worthwhile science content. However, in the water project, they were able to use the teacher's support to transform their question of convenience to a question that enabled them to learn about important science content.

Planning Procedures and Designing Investigations

Students' planning and designing improved considerably through involvement in PBS. Students' designs became more complex as students included more variables, considered more ways of measuring the variables, and used multiple samples. In some cases, students' procedures became more clearly defined; that is, they thought of ways in which they might represent their data, identified necessary materials, and divided responsibilities for conducting the investigation. However, some of the designs and procedures did not allow the students to answer the questions adequately because the designs included confounded and ill-defined variables.

In the earlier projects, students typically considered one variable with only two levels. By the water project, students considered multiple variables or single variables with several levels. For example, Alice's group decided to use several sources of water and multiple samples. The group decided to compare the quality of tap, toilet, pond, gutter, and river water, measuring pH and testing for fecal coliform in each sample. In Alex's group, students designed their study of the effects of water on seed germination by selecting water from three different sources and designing three conditions corresponding to the water sources.

Students also became more thoughtful and thorough in developing plans. For instance, Alice's group used the handouts given in class on bottle biology to plan how to construct two comparable decomposition environments, one with water and one with apple juice. Together they discussed the amount of apple juice to use, how often to water the environments, and the type of garbage to include in the column. Students were required by the teacher to make drawings of all items in each column before and after their investigation. In addition, this group decided to weigh each column weekly. They also created representations of their decomposition columns on their computers in order to record changes in their columns each week.

Although students' designs and plans improved, some students still confounded variables even though their teachers tried to help them understand research design. For example, in the decomposition project, students in Alex's group decided to construct a land environment using a plastic bottle and worms as the decomposers, and a water environment in a plastic tub with snails as the decomposers. They created this complex design because students wanted to work with snails. Although the teacher and peers in the class tried to point out problems with their design, the group failed to recognize that they were comparing water versus soil, worms versus snails, and columns versus tubs.

Conducting Investigations and Making Observations

Throughout the projects, the students took complete and precise observations. For example, even in the first project, students followed directions for conducting tests, completing the necessary steps and carefully recording results. Whereas in early projects, students tended to ignore their plans, they adhered more carefully to their plans in the later projects. For example, in the decomposition project, Russ made precise, complete observations in accordance with his original plan. He measured the weight of the worm bins at the beginning and end of the investigation, took weekly notes about the materials that had decomposed, and recorded his data as journal entries.

Interestingly, students often focused primarily on one variable while making their observations, even when their research designs were complex. For instance, Alice focused on how the decomposition smelled and paid less attention to other measurements. Similarly, some students became overly focused on one aspect of their project work failing to follow through on their observations. For example, after having taught himself how to use digital video technology, Alex used only the digital camera to take observations and did not take other measurements that were included in his plan.

Interpreting Data and Drawing Conclusions

Students' conclusions became more thoughtful and thorough based on the data they considered. Initially they simply described results, but later they drew conclusions based on interpretation of their data. However, when students made many observations, they sometimes did not base conclusions on the entire set. Reasons for their lack of attention to all of the data included not knowing why they had collected the data, how to represent this data, or how to synthesize the data. Although students created representations for presentation purposes, they did not always use these representations to help them understand the data or to draw conclusions. Initially most students did not provide explanations for their conclusions, but as the year progressed some students generated scientifically reasonable explanations based on their data and background information they had gathered. This was especially true when teachers required students to provide reasons for their conclusions and held them accountable for doing so.

For instance, in the second project Alice concluded that acid rain and non-polluted rainwater both cause organic material to decompose at the same rate, but she did not provide justification for her claim. Later in the water project, Alice provided an explanation for her findings. She concluded that the river sample had the highest fecal coliform level because of the presence of birds near the site. This was only a partial explanation because Alice relied entirely on fecal coliform readings, ignoring her pH data.

Russ's work in the decomposition project provides an example of how some students' representations of data were not linked to their conclusions. He had created a spreadsheet that included brief descriptions of the materials that had decomposed but he did not use the data from the spreadsheet to justify his conclusions.

Alex's work on the water project shows the difficulty some students had attending to all of the data that they had collected. He concluded in his investigation of the effects of three different sources of water on seed germination, that the seeds exposed to well water may not have germinated because of pollutants in the water. His conclusions about the order of seed germination were supported by the data he had collected. Although he had planned to collect data regarding the number of seeds that germinated, he did not do this. If he would have collected these data, however, he would have come to different conclusions.

An Example Case of Change in Inquiry Strategies

This example provides one case of change in inquiry strategies for science for a seventh grade student, Sally. In interviews, Sally reported that she enjoys hands-on learning, but she does not particularly like lectures and note taking. She is an outgoing girl who likes working with others. She is well organized, likes to complete work, and achieves good academic success.

In the first project, mystery powders, Sally's group did not create a plan to investigate the various unknowns, despite the teacher's suggestion. Based on handouts and prior activities, Sally created a chart of the tests that could be performed and what they indicated. Sally did not have any rationale for the order in which she conducted her tests. After each test, she recorded her data by writing a brief description of what she saw and then proceeded to interpret her results based on the chart. For example, after she performed a water test, she noted that the water caused the substance to clump together. She wrote that she might have flour, baking soda or powdered sugar. However, she never synthesized the data nor used the results from the various tests to draw conclusions about the identities of the powders.

In the decomposition project, Sally and her group developed a descriptive question: "Will orange or grapefruit peels decompose faster with worms?" Students selected their question without considering alternatives or discussing scientific merit. Basically, they wanted to use worms and in order to compare what types of materials would decompose faster in worm bins, picked the first two fruits listed in a book. In contrast to earlier efforts, Sally's group was more thoughtful and thorough as they planned. They considered many possible methods of measuring decomposition of fruit peels, including weighing the fruit, cutting it into equal sized pieces, and making drawings of its decomposition. By the end of their planning, they developed a complete, organized, long-term plan for creating an apparatus and collecting data. They selected measures, prepared a list of materials and assigned roles for gathering supplies. Following their teacher's instructions, they also created a chart to record observations. Finally, at Sally's suggestion, they assigned roles for taking observations. They decided that each member would observe a different bin, water it weekly and report their findings to the team.

Sally's observations corresponded to her plan. Each week, she measured the pH and temperature, noted the appearance and recorded information in her journal. However, she did not follow the plan completely. At the beginning of the investigation, her group made sure to add the same amount of water to each bin. Eventually, they stopped measuring the amount of water so that they added unequal amounts. Reflecting this error, Sally's conclusions respond to her original question and are supported by her data, but are confounded. Sally concluded that orange peels decomposed faster than the grapefruit peels because all of the pieces in the orange bin disappeared while the grapefruit bin had one piece remaining. However, she failed to acknowledge that the bins differed in both the kind of fruit and the amount of water, and limits her discussion to the variable she planned to alter. Her conclusions did not try to explain the differences.

In the third project, Sally and her partner, helped by their teacher, developed a relational rather than descriptive question, "If acid rain is added to an aquifer with limestone will the acidity be different when it comes out than when it comes out of an aquifer without it?" They originally asked a descriptive question, "How acidic is our rain and does it change over time?" but changed when they realized it was not feasible to collect rain samples before the project was due. After discussion with the teacher, the group developed an experimental design (two aquifers, one made with limestone and one without) and constructed their apparatus using previous instructions. Students developed a careful plan which included a list of materials and who was responsible for bringing them to school, ways to measure the pH, ways to describe the appearance of the two aquifers each day, and a chart to record observations. Sally followed her plan as she conducted the investigation. The group assembled materials, constructed their aquifers and showered them with an "acid rain" mixture of water and vinegar. Sally measured and recorded the pH before and after it went through each aquifer, and wrote descriptions. Sally's observations were complete and precise but her conclusions were based on only part of the data. She answered her question and concluded that limestone neutralized the effect of acid rain, but only cited data from the limestone aquifer.

Conclusions

The findings indicate that students' inquiry strategies in "real world" classrooms improve as they learn from projects. However, the improvement is not uniform across or within types of inquiry strategies. The findings also reveal the influence of motivation on how students engage in inquiry. Students' questions became somewhat more complex and feasible. Nevertheless, students often did not consider possible alternatives for their scientific merit. Instead, sometimes the questions were motivated solely by what appealed to students, such as liking apple juice, wanting to work with snails, or wanting to try out a particular scientific test. Over time their plans were more complete and specific, and the designs were more complex in terms of number and level of variables included. However, students sometimes did not realize that the design was inadequate for testing the question under investigation. For the most part students followed through on their plans and made careful observations. Interestingly however, they sometimes were inconsistent in measuring all variables; they got sidetracked by something of interest, such as the smell of the decomposition column. Data analysis and conclusions also became more sophisticated, rather than relying on descriptions of the results. When prompted by the teacher, students learned to provide justifications for their conclusions based on data and background readings. However, they did not always use all the data to draw conclusions, perhaps because they did not understand how to use the data to answer the question they had generated.

Overall the results offer evidence that project-based science is a promising way to promote the development of student inquiry as recommended by recent policy (National Research Council, 1996). The descriptions provide a realistic picture of seventh graders and demonstrate that progress is not smooth, uniform, or linear. The findings also indicate the important role that the teacher plays in facilitating inquiry.

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