Observations of urban middle school students engaged in technology-supported inquiry

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Recommendations about effective approaches to minority and urban education both by general and science educators (e.g., Atwater, 1994; Ladson-Billings, 1995; Lee, 1999) match the rationales for inquiry-based science. These include the need for exploration of phenomena related to students' everyday lives, for hands on experiences, collaborative work, conversations requiring the justification of different points of view, and multiple ways to express understanding.

Detailed accounts of students engaging in inquiry often come from demonstration sites or classes taught by researchers. There are few descriptions of students' initial attempts at inquiry, especially among urban students in regular classrooms. Our observations of middle class students illustrate patterns similar to those others have reported: a tendency to focus on procedures rather than content, ask low level questions, to neglect prior knowledge in making predictions, and to summarize rather than use evidence to interpret findings (Krajcik et. al, 1998). In addition, students master the mechanics of technical tools fairly easily, but need scaffolding to become thoughtful in creating scientific representations (Jackson, Stratford, Krajcik and Soloway, 1996). The purpose of this paper is to examine the behavioral patterns of urban middle school students when engaged in initial attempts of inquiry supported by technology.

Methods

Setting

This study focused on a subset of nine classrooms from the Center for Learning Technologies in Urban Schools (LeTUS) in Detroit, Michigan. We focused on two seventh grade teachers enacting the Air Quality curriculum over a two-year period. In addition, we focused on two eighth grade teachers enacting the Force and Motion curriculum- one for one year, the other over a period of two years.

Students

In each class, four students (for a total of 36 students) were nominated by the teachers for intense observation, based on the criteria of average school performance, talkativeness, and good attendance records.

Data Collection

Classrooms were taped across the curriculum units, approximately three times a week. For this study, we selected tapes from three events in each curriculum: investigations, technology use, and artifact creation. Approximately sixty-six hours of videotape were analyzed for use in this study. It is important to note that because the target students were filmed with their entire group, patterns of inquiry were based on student groups rather than individuals.

Analysis

Data were analyzed in several phases. First, a detailed summary of each videotape was prepared that contained descriptions of teacher and student behavior and conversation.

Second, each instance of teacher set up, wrap up and whole class discussions was coded for pedagogical strategies, stated goals, content accuracy, procedural accuracy, emphasis, and statements on group work. In this phase, student conversations and behavior were also coded for focus, use of justifications, content accuracy, process accuracy, interactions with group members, science language, affect, and actions. Third, the codes were synthesized across classrooms and then across teachers in order to form general patterns of student and teacher behavior during inquiry.

Background

In each curriculum, three types of inquiry events were chosen for analysis: investigations, technology, and artifact creation. In order to provide context for students' patterns of behavior, the following describes the inquiry events from the Force and Motion and Air Quality curricula in more detail.

Force and Motion Investigation

In the Force and Motion investigation, students grappled with the concepts of force, mass, and motion. Students were asked to a) design an investigation using a ramp, cart, washers, and set of blocks to determine the relationship between the mass of a moving object and its tendency to stay in motion, b) specify independent and dependent variables and decide what kinds of measurements to make, and c) use the data they collected to draw conclusions about how mass is related to Newton’s first law.

Technology in the Force and Motion Curriculum

Students used motion sensors to create representations of their own motion- in the form of a graph of distance and time- that were recorded on the computer screen in real time. The motion sensors allowed students to explore the components of motion, and more specifically, to describe velocity. The intent was for students to recognize that a faster motion created a steeper slope on the graph, and a change in direction of motion changed the direction of the slope. Each of these changes to motion, speed or direction, resulted in a different graph, implying that the description of the motion or velocity would also be different. To support students in thinking about their graphs a prediction, observation, and explanation (POE) cycle was used in which students first predicted what they expected a graph of their motion to look like based on previous experience. They then conducted a motion and generated a graph. Last they would compare their observed and predicted graphs, explain their motion, and reason about why the graphs may have been similar or different. They built on this experience to create predictions for their next POE cycle.

Artifact Creation in the Force and Motion Curriculum

Artifact creation and student presentations were included near the conclusion of the Force and Motion unit. Students created helmets to protect an egg during a collision and tested it using the same ramp and cart apparatus used in the investigations. They also used the motion sensors to collect data on velocity. The presentation was intended to be the integrating event for the unit as a whole. Preparing for the presentation was an opportunity for students to integrate and apply science concepts (force, Newton's first law, velocity, and acceleration), explain a collision, and test an experimental design. The presentation itself was an opportunity to share and defend ideas with the class and receive critical feedback.

Air Quality Investigation

In the Air Quality curriculum, students investigated the concepts of physical and chemical change. Students completed a series of experiments in which they combined different chemicals- such as vinegar and baking soda- made observations, and used evidence from the reactions to determine whether and why a physical or a chemical change had occurred.

Technology in the Air Quality Curriculum

Students created a dynamic computer-based model to support their thinking about a complex system, in this case the air quality in their community. Students used a technology-based learning tool called Modelbuilder that helped them to make qualitative models of cause and effect relationships. Students a) created "objects"- representations of real world entities in the model system, b) created "factors"- measurable, variable quantities of those objects, and c) defined relationships among those factors to show how they were interrelated by cause and effect. In a typical modeling task, a student might make an <u>object</u> that existed in the system of air quality called "vehicles". They would then choose a measurable quantity associated with vehicles that would affect air quality, in this case a <u>factor</u> called "amount of car exhaust". Next a student might make a <u>relationship</u> between the causal factor "amount of car exhaust" and the effect factor "air quality", and define the relationship as having negative effects, i.e. that as the amount of car exhaust increases, the air quality decreases. The Modelbuilder program provided facilities for testing relationships so students could demonstrate their understanding of the factors in the model, and a "factor map" to visualize the model as a whole.

Artifact Creation in the Air Quality Curriculum

As in the Force and Motion curriculum, students prepared for final presentations as a way to synthesize their knowledge- in this case, of air quality and the particulate nature of matter. Students were to present the sources and effects of a certain pollutant, and the pollutant's word equation, chemical formula, and number of atoms/elements. During the second year of the Air Quality curriculum, students were additionally supposed to present pollution data that compared their city to another in the U.S. Students were to conclude by connecting what they had learned in their presentation to the driving question.

Results

In this section, we describe the themes that emerged from student patterns of inquiry behavior across all three inquiry events: investigations, technology, and artifact creation. In each event and curriculum, we found that the urban students we observed behaved similarly to other students engaging in inquiry for the first time.

When we looked at urban students' patterns in inquiry, we uncovered three major themes. First, students can do thoughtful work in science inquiry, but need teacher support to concentrate on the science content rather than the procedures. Second, students have very little difficulty using the technology tools and evidence complex thinking about content while using technology. Third, students were highly invested during their inquiry tasks. By examining these themes we hope to provide educators with additional insight into the promise and challenges associated with implementing inquiry in urban and non-urban environments.

Theme 1: Thoughtful work is increased and enhanced by teacher press for understanding
During their initial attempts at inquiry, urban students behave similarly to other student populations observed previously by researchers including ourselves. The patterns suggest that inquiry does provide opportunities for students to grapple with and build conceptual science understanding. However, these opportunities are not fully realized unless teachers provide extensive scaffolding, such as probing, coaching, and monitoring, to help students to be thoughtful. In the absence of this scaffolding, students are likely to focus on the procedural aspects of accomplishing their work. Students are more likely to be thoughtful and engage in conversations about the science content embedded in the inquiry activities when teachers press them for understanding.

Students' tendency to proceduralize their work was found in instances where students conducted investigations and constructed artifacts. For example, in the Force and Motion investigations, student conversations primarily focused on assigning tasks, figuring out what needed to be done, and- while doing the investigation- alerting others that the cart was about to be released so they would stand by to take measurements. Much less time was spent pulling evidence together, and interpreting that evidence in relation to the science concepts being investigated. When constructing artifacts in both the Force and Motion and Air Quality curricula, students devoted themselves to distributing work among their group members, creating visual aids, and checking that they had completed all of the presentation parts. These procedural behaviors often eclipsed what we had hoped to be an opportunity for students to construct and synthesize their understanding of science content with each other. However, we recognize that the considerable scaffolding of the presentation task in the form of guidelines and instructions outlined in the curriculum materials may have overwhelmed the students with the amount of detail included and steps to be completed.

In our study, there were instances of students attempting to take advantage of the opportunities provided them in inquiry to produce thoughtful work and conversation. In the Force and Motion investigation, some students thoughtfully designed an investigation with attention to control, independent, and dependent variables. For instance, as Laura was filling in her variable chart, she remarked "the thing you change is the mass of the cart", referring to the independent variable. Her group went on to identify the dependent variable as the distance the cart traveled, and the control variable as the height of the ramp. In reference to the control variable, Laura said, "there are two things, the height of the ramp and the washers." Another girl challenged, "no, you have to change that. Controls are height of ramp and mass of blocks." Students also produced thoughtful hypotheses and conclusions in this investigation, such as "I think that as the mass is added to the cart the easier the blocks will be to move and they will move a greater distance."

As has been seen before in other literature on students in science inquiry, students summarized and synthesized their data, but tended not to refer back to the content they were investigating to draw full conclusions. In the Force and Motion investigation, when forming conclusions, students summarized what happened, linked back to their hypothesis, used their data as evidence, and determined whether their hypothesis was correct. However, students did not refer back to Newton's first law to conclude that an increase in mass makes it more difficult to stop an object. For example, in Kevin's group, he reported that, "our data supported this because with 2 washers it went 24 mm, 4 washer 28, right? 6 washers 36. What is the answer to the question, the easier it is to stop?" Another student in his group- James- responded "it is easier to stop the cart with 2 washers." The group also concluded that upon impact with a heavy cart, the blocks at the bottom of the ramp moved farther. Eugene summarized the group's findings: "Our hypothesis was right. The more mass in the cart the easier the blocks are to move."

Students in the Air Quality curriculum also infrequently referred back to the content- in this case, the physical and chemical changes- they were investigating. One example where students did use experimental evidence on their own to form a conclusion occurred during an experiment in which students were to add sulfuric acid to limestone and observe the chemical reaction that occurred- evidenced by bubbles of carbon dioxide gas forming on the surface of the limestone. The students did not observe the bubbles, and so three students declared the reaction a physical change, with the justification that "nothing happened". A fourth student challenged that conclusion, explaining that if "nothing happened" then no change of any kind- physical or otherwise- had occurred. What followed was a heated debate in which students used the physical and chemical change definitions and previous experiments to support their argument. In the end, the students were not able to resolve their differences, but were able to engage the content in a thoughtful and meaningful way.

Student work during investigations and artifact creation could have benefited from increased teacher press for understanding. Teachers' instructions for the presentations tended to focus on completing all steps in the guidelines, and producing a presentation with polish and style. This probably influenced students' tendency to do the same when preparing for their presentation instead of focusing on a synthesis of content understanding. Classes where teachers emphasized content yielded more substantive student presentations.

Even the examples of students' more thoughtful investigation design, hypothesis, and conclusion generation could have been scaffolded to enhance understanding. For instance, when Laura's group was identifying variables the teacher could have asked them to explain what it meant to have control variables in an investigation. In the example of Kevin's group making a conclusion, the students could have been pressed a little bit farther to apply the distance that the blocks moved to how difficult it was to stop the cart- and hence to Newton's first law. When students debated their conclusions in the Air Quality investigation, the teacher could have encouraged them to make more careful observations and helped them to articulate the difference between a physical, chemical, and "no" change in the context of the investigation they had just conducted.

An instance in which a teacher's press did lead to more thoughtful work and more accurate science understanding occurred in a class where students were giving their final presentations. When the teacher set up this activity, she had initially focused on the inclusion of key vocabulary words such as force, velocity, acceleration, and Newton's first law in students' presentations. Students did just that--they used the words but often inaccurately and without context. For example, in Kevin's group presentation, he pointed at the ramp and said, "this is where acceleration occurs". Next he showed his velocity-time graph, explaining, "the cart hit the barrier at three seconds velocity. The velocity was 1.5 when it hit". After two student groups had presented, the teacher stopped the class and declared they all would have failed if that had been their "real" presentation. She told them they could not just use the words without meaning, and that they had to apply what they had learned to Newton's first law. Students were assigned to improve their presentations over the weekend.

The second time around, Kevin's group provided a much more detailed and scientifically accurate explanation of the motion of an egg and cart rolling down a ramp and colliding with a barrier. "When the egg went down the ramp, when it started it was zero. Then acceleration started. When it hit the end of the ramp velocity went back to zero and the egg flew off the cart because an unbalanced force acted on it. This is related to the ballistic cart because an outside force acted on the cart but not on the egg, causing the egg to fly out of the cart. But our egg was safe because it was wearing a helmet." Kevin's explanation of the exact same velocity-time graph showed similar improvement in accuracy and detail. " It [the egg/cart] hit at 1.5 seconds and 3 meters." Pointing at the positive slope section of the graph, he said, "this is the acceleration line." Then he pointed to the first horizontal section of the graph and explained, "this before it starts." And pointing to the downward slope, he concluded, "this is after it hit." The improvement of the presentations in this class illustrate the progress that can be attained when teachers provide targeted feedback to student work, press students to produce a thoughtful product, and allow time for students to make revisions.

Theme 2: Technology offered opportunities for complex thinking about content
Using the two types of technology- Modelbuilder and motion sensors- gave students opportunities to explore the science content and demonstrate their understanding. In the case of Modelbuilder, students created relationships between sources and effects and then had to explain them using their knowledge of air quality. In the case of the motion sensors, students explored the concepts of velocity and acceleration using the graphs they generated from their motion. Notable in both curricula was the ease with which students used the technology. Students learned how to use both technologies very quickly, and went immediately to exploring the task at hand. For example, in the Air Quality curriculum, a student followed a teacher's demonstration of how to build a factor precisely on her own computer. As soon as the demonstration was complete, this student immediately discussed and built additional factors with her group with no difficulty. The group completed their assignment so quickly, they proclaimed proudly, "we could finish this [model] today!"

As with the investigations, students had a tendency to proceduralize their technology work unless they were pressed for understanding by their teachers. For example, students using Modelbuilder tended to concentrate on checking for model completeness (i.e. the number of factors and relationships) and inputting content into the appropriate spaces. In the Force and Motion curriculum, some students were more worried about replicating their teacher's graph than the concepts the graph illustrated. For example, Lakeeya and Kyra's group arbitrarily decided on a different motion for their next trial when their graph did not conform to their teacher's demonstration graph. The demonstration graph of distance v. time showed a zig zag line, which students were meant to infer was created by moving away, standing still, and then moving forward toward the motion sensor. But instead of interpreting the graph, the group tried to replicate it by moving in a zig zag pattern as well.

In other cases, students were more thoughtful about motion in planning a specific strategy to achieve a desired graph. After Eric's group had completed a motion, they looked at the graph and decided to try a different one. In the next motion, Eric said he would walk for two seconds and he would get to "here"- and he was pointing at the distance axis of his graph, a little away from the origin. From this example it was clear that he was linking his position and movement to its representation on the graph.

The graphs produced by the motion sensors gave students the opportunity to think more deeply about motion itself. One group of girls after completing three motions away from the sensor at different speeds attempted to answer the question, what is the pattern or trend of the graph? Natasha answered, the "y axis is the position and the x axis is time" while pointing at the correct axes on the graph on the computer screen. A girl working with Natasha asked, " what is the pattern or trend, what does that mean?" The group looked at the graphs and then Starleise tried to explain, "they all ended going in a straight line." But the girl still did not understand, so another responded, " they all had slope." In a different instance, a student related a positive slope on a graph to the correct motion. When his teacher described a positively sloped line as illustrating a forward motion, he objected. "We did a motion that created a graph like that one and we were walking backward, away from the motion sensor", he said. This student not only linked the conversation with his teacher to a previous lesson but also understood the graph in the context of the motion that created it.

Like the motion sensors, Modelbuilder also allowed students to think complexly about content. Initially, students built direct relationships between a primary source and air quality (i.e. carbon monoxide to air quality). Later in the curriculum, students built more complex relationships between a primary source, a primary effect, and air quality. For example, a student group created a relationship between the release of sulfur dioxide by factories and the formation of acid rain. Then they connected acid rain to the damage it caused to trees or buildings. More complex relationships required students to think more deeply about the direction (increase or decrease) of those relationships. While her partner was building a relationship between acid rain and their factor "amount of dead plants", Clarice said, "hold up, as the amount of acid rain increases, the amount of dead plants INCREASES too, don't it?" This complexity also provoked discussion between students about sources and effects of air pollution. For example, Brian suggested to Latia that they make a relationship between acid rain and plants. After she built it, he said to her, "hold up, we should do amount of plants, because acid rain doesn’t make them grow slower". Another student in his group- Damon- disagreed, "yes it does!" Damon consulted his reference materials and read, "it makes trees and plants grow slower". Brian insisted that the quote Damon referred to concerned sulfur dioxide, not acid rain. Latia asked what she should write, but because the boys couldn't resolve their differences, she decided for the group. In this conversation, students not only clarified their understanding of sources and effects of air pollution, they used reference materials to back up their arguments.

The quality of student engagement with science content or process during technology use was often a direct result of the teacher's emphasis during task set up and monitoring. In the Force and Motion curriculum, the two teachers differed in how they introduced the motion sensors. The teacher who stressed the replication of her graph had Lakeeya and Kyra in her class- the girls who concerned themselves with this more procedural task as well. The teacher who pressed students to understand the representation of motion as contained in the graphs had Eric's group in her class- the group that made efforts to plan motion strategies based on inferences of their graphs. This same teacher, however, could have monitored Natasha's group more closely, and helped them with their confusion about slope and patterns in graphs.

In all of the Air Quality classes, teacher emphasis on completing a certain number of factors and relationships mirrored students' concern with the number of model parts. Teachers rarely gave feedback on students' relationship explanations and did not provide opportunities for student groups to share their models with the rest of the class. These strategies could have facilitated thinking and conversation more focused on content.

Theme 3: Students were highly invested in inquiry

The urban middle school students in our sample were hardworking, conscientious, and invested in all three inquiry events. For example, all students in each group in the Force and Motion investigation participated. They divided and shared roles and tasks, conducted their work carefully, checked for completeness and shared their data so that every student had the same measurements. Students in the Air Quality curriculum were also careful to follow procedures correctly and make exacting observations, although they tended to share roles and responsibilities less. Teacher monitoring for cognitive engagement and accountability and a task structured with more to do, could have facilitated more equal participation and the ability of students to take more active roles.

In creating artifacts, students in both curricula carefully constructed their required visual aids, giving each other feedback on artistic merit and understandability. Students were attentive to the presentation guidelines and made a sincere effort to complete all parts- checking each other constantly to see who was doing what and that everything was covered. They also continuously asked for clarification- from their teacher or fellow students- on what they were supposed to do to fulfill certain guidelines. In addition, students proudly showed their visual aids to others in their class. Students' earnestness toward their inquiry tasks shows that they felt a sense of ownership and were committed to producing work in accordance with teacher expectations. From this evidence, and from the examples of thoughtful work provided previously, we believe that students are committed to doing what they are asked to do. When pressed accordingly, urban middle school students can take advantage of the opportunities provided in an inquiry-based curriculum to grapple with advanced science content and develop their understanding.

Discussion

Inquiry is possible in urban environments. Our findings indicate that in their initial attempts at inquiry, urban students are motivated to meet teacher expectations, and have difficulties with science concepts and process skills similar to students others have observed in non-urban settings. They tend to focus on procedures when engaged in inquiry activities such as investigations, technology and artifact development, just like students in more affluent suburban communities (Krajcik et. al, 1998). In investigations particularly, they often neglect to apply experimental evidence, and struggle to understand some of the more difficult science concepts; as others report (Krajcik et. al, 1998; Kuhn, 1989; Lunetta, 1998; White & Frederiksen, 1998). Learning to use technology, however, was not difficult for students in these urban classrooms.

As in other settings, urban students exhibit thoughtful engagement with science concepts during inquiry in both their work and conversation. This thoughtfulness was facilitated when teachers pressed them to focus on the science concepts, monitored student work, and allowed for cycles of revision. The latter may be one of the differences between press in this and other settings. In suburban settings, students often revised and improved their work at home (Krajcik et. al, 1998), while revision and homework was less frequent in the current study. Effective use of time in and outside of class might better exploit the benefits of inquiry.

It is important to note that these urban teachers did attempt to scaffold students' science understanding. However, most of their support efforts occurred at the beginning of inquiry lessons. Additional support from teachers during and after inquiry lessons- such as probing, monitoring, and helping to synthesize student work- would have helped students to continue to advance their understanding. We recognize that it is challenging for teachers to transition to inquiry practice, even when they receive extensive professional development and models in their curriculum materials (Marx et. al, 1997; Scott, 1994). Likewise, some of the more complex inquiry tasks may need to be redesigned to move students beyond procedures and toward engaging in content.

Our findings point to some of the challenges of promoting science understanding through inquiry in urban and non-urban settings. The challenges include careful design of inquiry tasks, scaffolding students in their understanding of science content and process skills, and helping teachers to promote understanding with scaffolding strategies. Teachers like other learners need to be scaffolded in their initial attempts at using inquiry as an instructional strategy in the classroom. The challenges we have faced promoting inquiry in urban classrooms shows that doing inquiry is complex but promising. We encourage those who are attempting to initiate inquiry in science education to attend to the interplay between students' behavior during inquiry, teacher press, and curriculum design.

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