Chapter 14

Action Experiments: Are Students Learning Physical Science?

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Rationale

There is a great national need to improve science education in the United States, as evidenced by how American students are not prepared for the workplace in our increasingly technological age. The recent Third International Mathematics and Science Study (TIMSS) report indicates that eighth grade students in the United States are ranked in the middle of eighth graders from 41 countries in the study (Peak, 1996; Schmidt et al., 1997), while fourth grade students in the United States rank second of 26 participating countries, only behind Korea (NSTA, 1997). These results suggest that we need to continue our efforts at improving science education countrywide, if we are to achieve number one status in the world by the year 2000, a goal set by then President Bush of the United States of America (National Education Goals Panel, 1991).

Objectives

An important approach to reaching this goal is to teach science to teachers, both practicing teachers and prospective teachers who are still in training. There is an amplification effect, when one teaches teachers, as each teacher will interact with 30–150 students per day, depending on whether they are teaching in elementary schools, middle schools, or high schools. It is critical to teach science in an active way that is consistent with how people learn, if we are to have an impact on the teaching and learning of our K-12 students.

This paper set describes action experiments that are utilized to teach graduate level physical science to practicing elementary school teachers. The idea behind these action experiments is to get the teachers in the graduate level class to be students, asking questions, gathering data, making inferences, and building understandings about the natural world. If teachers experience learning in this way they can encourage their students to do likewise. Hereafter in this study, the practicing teachers will be called teacher-students, because they are both teachers of children and graduate students in their physical science classroom.
Action experiments are experiments in which the participants must act or 'move to action'. The teachers must become active learners of science. I organized the teacher-students into cooperative groups, and asked them to select action experiments from a series of possible experiments suggested to them. The experiments call upon their experiences from living in the physical world. To learn the concepts of physical science, fancy equipment is not needed. Most experiments utilized supplies that are readily available in their homes. By using materials with which they are familiar, teachers will start to see physical science all around them. It will empower them to use such everyday supplies to teach science to the children in their elementary school classrooms.

This paper examines the discourse among teacher-students and between the instructor and the teacher-students, for improving the learning of physical science. This discourse occurs in the classroom, on the worldwide web, through field experiences, and in their writing.

Theoretical underpinnings

The teacher-students work in collaborative groups (Johnson et al., 1991), to learn the science content, using the language and discourse of science (Lemke, 1995). There are no lectures given, so the teacher-students must construct their understandings based on their prior knowledge and their experiences in the physical science classroom, in their reading of the textbook (Hewitt et al., 1994), with their web-based learning, and during their field experiences. Constructivism is the primary theoretical underpinning (Glaserfeld, 1989; Tobin, et al., 1990; Marzano, 1992; Tobin, 1993; Tobin and Tippins, 1993; Brooks and Brooks, 1993; Appleton, 1997).

Methods

Data sources include audiotapes and videotapes from the physical science class, dialog journal postings on the web, postings of action experiments on the web, and visits to teacher-student classrooms. I utilized fourth generation evaluation methods in this research study (Guba and Lincoln, 1989).

Electricity, magnetism, sound, light, and chemistry were some of the topics included in this course. Simple experiments are selected from several books of basic experiments in physical science (e.g. Churchill et al., 1997; Challoner, 1995; Feldman, 1995). For instance, for the unit on sound, experiments from Churchill et al. (1997) included 'Noisy paper', 'The screamer', 'The tapping finger', 'The listening yardstick', 'The strange vibrating bowl', 'Can you tune a fork?', 'Tuning a glass', 'Tune more glasses', and 'Seeing sound waves'. After being alerted to the materials that would be needed in the experiments by the instructor on the website, teacher-students brought their own equipment from home to the class. This encouraged teacher-students to take ownership to their experiments and ideas. For instance, in the unit on sound a group of four teacher-students each brought country-type
musical instruments (e.g. wash tub with string attached to make a stringed instrument) to class, and played a song. After singing and playing a song about our class, they showed how to create different pitches on different types of 'instruments'.

Each day after performing action experiments the cooperative groups shared their learning with the instructor and the other groups in the class. Each group reported orally on their understandings and learning in the experiments of their choice. Everyone had a chance to contribute to the dialogue and learning. Sometimes debates about interpretations of data occurred.

There was a five-week field experience after the first three weeks of intensive classroom experience. This was followed by one additional week of intensive classes, in addition to a teacher-as-researcher week-long conference in the evenings. During the field experience each teacher-student wrote their favorite action experiment on the website for all teacher-students to read. The website postings served as a reminder of what we had done in class and what we learned. This serves as a device to get the teacher-students to use the language of science (Lemke, 1995) to describe their favorite experiment, and to reflect on the experiments that their fellow teacher-students have chosen to share with the others. All teacher-students needed to utilize the language of science and share their understandings of the physical world. Most of the teacher-students taught summer school during this field experience, so they had opportunities to test their new understandings and ways to teach physical science with the children in their classrooms. One of the advantages of teaching a group of teacher-students is that you get feedback very quickly on the quality of the learning, on what worked and what did not, in the physical science course designed for the elementary school teachers.

Some teacher-students created experiments that went beyond the ones offered to them. One teacher-student demonstrated the Doppler shift in which the frequency of sound is shifted through the motion of the object making the sound or the receiver of the sound. A number of physical science concepts (i.e. especially frequency and motion) must be understood to explain the Doppler shift. First, a teacher-student learns that sound is a longitudinal wave with compressions and rarefactions with an amplitude and a frequency. The teacher-students observe that a wave of compression (i.e. the vibration) moves from one end to the other end of the slinky when a lateral impulse is given to one end of the slinky while the other end is held stationary.

Findings

Teacher-students with experience in elementary school teaching, in general, had little background in the topic of sound, except for a few who have played musical instruments. The instructor encouraged the teacher-students to select several experiments to do, utilizing their textbook and their prior knowledge to see if they could make sense of sound.

Some teacher-students tried an experiment at home, and then brought the materials from home into the classroom to share with their collaborative group. For
example, one student, Sabrina (a pseudonym), decided to research sound, and learn about the Doppler effect, by recording for herself what a horn sounds like when it approaches a stationary tape recorder and as it moves away from the tape recorder. Therefore, she did the experiment on her own, and brought the tape recording to class. It was an impressive recording. Sabrina learned science content by preparing this tape, trying to make sense of her data, and sharing her results with the other teacher-students in the class. By Sabrina using the language of science, the instructor could help her with some misconceptions.

The instructor could tell that even the teaching assistant, Bruno (a pseudonym), did not have a full understanding of all the concepts on sound and asked him to prepare a similar tape and explain the concept of the Doppler effect to the second section of graduate level physical science class. The instructor did not help Bruno when he collected the data, as he tried to make sense of the recording. Below is a transcript from class. There are many misconceptions, embedded within his dialogue:

**Bruno**

So, think about, so think about the slinky, and think about you’re standing here in the middle of the slinky. OK. Now. And, and it *sounds* . . . OK? So what’s going to hit you, first? I mean, just, just, just say, you’re going to get hit by two things. What are you going to get hit by? Compression and then a, and then?

**Teacher-students** [in unison]

A rarefaction . . .

**Bruno**

OK. So then you’re going to be hit by a compression and a rarefraction [sic]. All right, so, when you are hit by a compression and you’re hit by a rarefraction [sic], all right, and you listen to sound. It’s very easy, I want to do it, I want to tell you so bad, but I know the concept I want to tell you, but I want you to construct it in your mind.

**Bruno** [continuing]

OK, now, say, when I started honking the horn, and it was *real* loud, and then it goes down, and then it, as it passes me, it goes back up. OK, all right, so think about the wave, think about the whole wave. All right, now, think about I’m in the middle of a wave. OK, when it’s loud, do a lot of waves hit me? As opposed to when the sound, when it’s, it’s down, the pitch is low?

**Teacher-student**

Yeah.

**Bruno**

Which way would a lot of waves hit me?

**Teacher-student**

When it’s up. When it’s a compression.

**Bruno**

Well, when will a lot of waves . . . I’m talking about waves now, and the number of waves?

**Teacher-student**

When it’s a compression.

**Bruno**

OK, so, well, how is it going to sound? Here I am, standing, louder, or . . .
Teacher-student
Louder than before.
Bruno
OK, at first, it’s going to be louder, and after a while it’s going to go . . .
Teacher-students [in unison]
Lower.
Bruno
It’s going to go lower. Are you saying lower is a higher frequency or a lower
frequency? Define higher and lower frequency. Is lower a higher frequency?
Teacher-student
If the pitch increases, it’s higher.
Bruno
OK.
Teacher-student
If the pitch decreases, it’s lower. Is that what you are looking for?
Bruno
OK, let’s talk about pitch. Let’s go to pitch. OK, let’s talk about pitch. All right
now.

Transcribing this lesson was an important way for the instructor to see how
confused individuals can be on the basic concepts. When Bruno was explaining
the experiment in class, he confused even the instructor. When Bruno said, ‘When I
started honking the horn, and it was real loud, and then it goes down, and then it, as
it passes me, it goes back up’, he confused the concepts of amplitude and frequency
of sound. Bruno also mispronounced the word, rarefaction, using ‘rarefraction’
instead.

It was not clear why Bruno suggested that the teacher-students imagine that
they were traveling along the sound wave. What insight is gained by the construc-
tion that the teacher-students imagine they are in the middle of the wave on the
slinky? The molecules in the medium only oscillate as the wave passes through
the medium. Sound is the transmission of the vibration. Perhaps Bruno was trying to
understand what happens to the sound in order for the pitch to be different for the
receiver. With the Doppler effect the vibration itself remains the same, it is that
either the vibrating object or the receiver of the sound is moving, which changes
the frequency at which the vibrations are received.

Bruno was trying to use a constructivist epistemology in letting the teacher-
students construct their own knowledge, as evidenced by his saying, ‘It’s very easy,
I want to do it, I want to tell you so bad, but I know the concept I want to tell you,
but I want you to construct it in your mind.’ However, Bruno did not have a clear
idea of what sound was, so he could not answer the teacher-students’ questions. In
fact, he confused the teacher-students. However, this generated dissonance in the
teacher-students’ minds which they wanted to clear, thereby motivating them to
think about sound more deeply.

Bruno also experienced dissonance as his ideas on sound were not consist-
et with those of other students. During the field experience, Bruno did come to
understand some aspect of the frequency of sound waves and the Doppler effect by
suggesting an experiment that teacher-students could use in their classroom.
Here is a teaching tip on the Doppler effect. Model frequency with a student slowly rolling golf balls, or other similar balls, down a long chalk tray at regular intervals, with the balls representing wave crests. Have a second student stand at the other end of the chalk tray, collect and count the balls, measuring the time to calculate frequency. To demonstrate the Doppler effect, have the receiving student walk toward the sending student counting the number of balls collected in the same time period. Collecting the balls while walking away will produce fewer balls in the time period, representing a lowered frequency. Your class is now ready to discuss the Doppler effect. (Gordon, 1991)

Bruno’s construction conveys the idea of the change in frequency when the receiver of the ball approaches or recedes from the person who is rolling the ball towards the receiver. One problem with this construction, however, is that with sound there is no mass being transmitted, it is only the vibration that is moving.

Another teacher-student, Paulene, whom the instructor had visited in her elementary school classroom during the academic year between the first two summers of the program, asked a question on the Doppler effect in the dialogue journal on the web:

Do you know if the Doppler effect can be heard if the sound source is stationary, but the listener is moving? For example: If a car drives by a non-moving car that is blowing its horn, will the moving car hear the Doppler effect? I had problem figuring that out. I know I can hear the Doppler effect if the sound source is in motion.

A teacher-student in Paulene’s dialogue group wrote back the following entry, in response to Paulene’s question on the Doppler effect:

As for the Doppler effect, I believe, that the car has to be moving because, according to our physical science book (Hewitt et al., 1994), the Doppler effect is a change in frequency of wave motion resulting from motion of the sender or receiver. I think the key words are ‘motion of the sender or receiver’. On page 263 in the same book, it describes the bug moving in the water so I believe something has to be moving in order for it to happen. However, I could be wrong... let me know!!!

It was obvious that the Doppler effect was still not understood by the teacher-students. Therefore, after reading these dialogue journal entries, the instructor wrote back in the dialogue journal and suggested to Paulette that she try to do an action experiment herself, as we did in class. Penny, the instructor, wrote:

You asked an interesting question about the Doppler effect — whether you get the Doppler effect if the sound is stationary and the listener is moving. I was glad to see the discussion between you two [of you in the dialogue journal] on this. It is a simple experiment, so you might want to try to do it. You get a portable tape recorder and drive past a friend who is sitting stationary in the car blowing the
horn steadily. You drive past the stationary car (with its horn blowing) and record what you hear. It would be a good experiment to include in your field experience for me. You could save the recording for your students.

Paulette conducted her field experience about sound. She was a researcher, and utilized the world wide web, her textbook, and the dialogue journal to discuss her ideas on our website. She chose her field experience to answer a question she had in her mind, based on what she did not understand in class. Paulette wanted to extend her knowledge:

My reason for selecting this experiment on sound is . . . I couldn’t visualize the Doppler effect after we discussed it in class. Before conducting this experiment, I thought it would seem sensible to assume the sound of a passing car would remain monotonous and not change pitch since the sound itself had no pitch variations.

Paulette found an experiment on the Doppler effect from one described on the website for the Exploratorium Museum in San Francisco (<http://www.exploratorium.edu>). However, she innovated and modified an experiment that she found on the world wide web and so that she could use materials that she had available. Paulette wrote the following in her field experience paper:

I wanted to keep the experiments simple, so I decided to use things that were accessible around my house. The items I used were: a small battery-operated alarm clock, a strong string (about two yards), and masking tape. I assembled the instrument by using the masking tape to tape one end of the string around the alarm clock. I wrapped both the string and tape around the clock tightly. I made sure not to tape the alarm clock buttons. I rotated the alarm hand until it buzzed. I then had a buzzer. I held the opposite end of the string and used my other hand to extend and hold some of it for leverage.

I twirled the buzzer around my head. I noticed how the pitch changed as the buzzer approached and moved away from me. When the oscillator (i.e. the buzzer) moved toward me, it, in effect, caught up slightly with its sound waves. With each successive pulse of the buzzer, the sound source was a little closer to me. The waves were being squeezed together, and more of them reached my ear each second than if the buzzer was standing still. Therefore, the pitch of the buzzer sounded higher. As the buzzer moved away from me, fewer waves reached my ear each second, so the resulting pitch sounded lower. The frequency of the buzzer itself did not change in either case. For my ears to detect the Doppler effect, the buzzer had to be moving toward or away from me at a minimum speed of about 15-20 miles per hour. As the buzzer moved faster, the effect became more pronounced. The pitch of sound increased when the buzzer moved toward me and decreased when it moved away. After this experiment, I had a better understanding of the Doppler effect. By twirling the buzzer, I could hear the ‘neeeeoowwm’ sound.

Paulette really had her mind on her experiment, as she innovated and tested her ideas. These ideas became clear to her through experimentation. The experiments raised new questions in her mind. She reflected further (Schon, 1983) in her field experience paper:
I wanted to take the experiment a step further and hypothesized if there would be a Doppler effect if the buzzer was stationary and I was in motion. I tried doing this by putting the buzzer in the middle of the floor and running around it as fast as I could I am not a runner. I assume if I were to run around the buzzer at the same speed as I twirled it — about 20 miles per hour, I would hear the ‘neeceecoowwm’ sound. At barely four miles per hour, I did not hear the Doppler effect. I also tried running closer and farther away from the buzzer, to see if that would make a difference (but it didn’t).

I also experimented moving my head while I slowly twirled the buzzer. I thought I would not hear the Doppler effect, but I did. No matter how slowly I twirled the buzzer, my head moved slower than my rotating arm. This proves that the Doppler effect can result even with two moving objects. For example: When a car, blowing its horn, passes a slower moving car — the slower car will hear the Doppler effect. These experiments helped me realize that the Doppler effect is a result of a change in frequency due to the motion of the source or receiver.

A Perspective of Student Learning

To understand how a teacher-student comes to know and to learn science, it is best to listen to what Paulette reflects on her experience after the course is finished:

I gained knowledgeable insights on how students learn, both as a teacher and as a student. I recognized that students learning about their surroundings naturally and enthusiastically, and with proper techniques, can be utilized for effective teaching. Research supported the conclusion that to improve teaching we must first understand how students learn.

Richardson, as cited by Collins and Spiegel (1995), stated that ‘research is conducted by practitioners to help them understand their contexts, practices and, in the case of teachers, their students. The outcome of the inquiry may be a change in practice or it may be an enhanced understanding’ (p. 118). Collins and Spiegel (1995) further state, ‘Whether it is termed action research, classroom research, or practical inquiry, the genre formalizes an aspect of teaching that expert teachers have known about and employed for a long time. They observe situations in their classrooms that are less than optimal, they identify the problem, they think about what and how to change, they make the change, and they evaluate the impact of the change on the situation and begin again’ (p. 118).

In the past two years, I have examined how students learn, and how they process science skills. Research and experience reveal that, in many cases, traditional science classroom instruction led to less science understanding than I anticipated. ‘When the teacher alone assumes the role of information giver, students may misinterpret the teacher’s explanation, ignore the teacher or decide that “school” science does not make sense in “real life”’ (Rutherford and Ahlgren as cited in Science for All Students, p. 36, 1997). Students often hold beliefs that are at odds with commonly accepted scientific thought. These misconceptions must be identified and confronted, before effective learning can take place (Florida Department of Education, 1993, p. 41).
The ideal learning environment, to benefit the students, should involve cooperative learning, concept and process learning, hands-on experiences, and self-assessment techniques. The ability to self-assess understanding is an essential tool for self-directed learning. Students need the opportunity to evaluate and reflect on their own scientific understanding and ability. Before they can do this, they need to understand the goals for learning science. Through self-reflection, students clarify ideas of what they are supposed to learn. They begin to internalize the expectation that they can learn science (National Research Council, 1996).

Considerable information has been accumulated on the way students learn. As a student, I have explored the concept, skill, or behavior with hands-on or minds-on experiences. I also elaborated and evaluated my understanding of these ideas by applying them to other situations. Additionally, I discussed and compared ideas with other students, while evaluating my own understanding.

In physical science class, my assignments were to read the textbook chapters, answer the questions at the end of each chapter, and select two activities to demonstrate in class, relating to the immediate lessons. These activities were done in class with preselected groups of four students. At the end of the term, I conducted a field experiment — a reflective thinking of what I read in the text, and of what I discussed and observed in group demonstrations. Reflective thinking helped me to store information in long-term memory, and assimilate what I learned. One of the advantages of reflection was that it helped to connect the concepts, and made ideas more meaningful.

Learning had a greater impact when it was combined with hands-on activities. By doing the hands-on activities, I was able to demonstrate what I read and how I understood it. I had a language to communicate what I understood, by reading the textbook.

Students learn best when they are allowed to construct their own understanding of concepts over time, and by active engagement in the learning process. If students engage in exploratory investigations and are allowed to construct meaning out of their findings, they can propose tentative explanations and solutions, and relate concepts to their own lives. That is how meaningful learning will take place.

In our groups, we selected activities we found interesting and/or which made us curious. We explained our ideas through demonstrations of the activities to the other students in class. The activities were simple and the materials were easy to obtain. As a group, we figured out concepts by thinking it through, and experimenting with what worked and what didn’t work. We experimented and predicted what would happen when changes were made. We asked questions for clarification, and hypothesized how activities can be extended. The class members observed, as we discussed differences between the predictions and observations. We learned from each other by observing group activities done in class.

As we experimented, we referred to the textbook constantly, to make connections to related ideas. This allowed us to use the language necessary to communicate our findings or understandings between the group members, and to the class. The more we experimented, the better the text’s terminology could be understood.

As a co-learner, I listened carefully to other students’ explanations and questions. I justified my explanations and sometimes transferred an explanation to other situations in order to fully grasp a meaning. To understand a concept, I would ask myself questions that probed into how and why I thought of something. This helped to reveal how I was thinking, as I tried to restructure erroneous or incomplete ideas.
To understand science concepts, I predicted, observed, and explained my findings in conducting my action experiments. These strategies helped to support correct predictions, and helped to challenge incorrect ones.

After a concept or an idea was discussed in class, I reflected and evaluated my understanding of it. In this way, I selected to either assess my understanding or to direct my learning. For example, for my field experience, I experimented with the Doppler effect (the 'neeeeeeowwm' sound we hear from a passing car) because I could not visualize the Doppler effect after we discussed it in class. Before researching the topic by conducting the experiment, I assumed the sound of a passing car would remain monotonous and not change pitch since the sound itself had no pitch variations. I corrected my assumption after I researched it in the field. After the experiment, I realized that the Doppler effect was a result of a change in frequency due to the motion of a source or receiver. Through this example, it was obvious how learning was sustained with the application of hands-on activity, and by using reflective and self-assessment procedures.

As Paulette returns to her elementary school classroom, she plans to utilize action experiments in her classroom. She will do this in the context of action research (Collins and Spiegel, 1995), using fourth generation evaluation (Guba and Lincoln, 1989), this is all part of a graduate program PROMASE (PROgram in Mathematics And Science Education), funded by the National Science Foundation (NSF) through the Miami Urban Systemic Initiative (USI).

In the physical science course, she also read and critiqued the recently published collection of action research experiences of elementary school teachers (Gilmer and McDonald, 1977) from the NSF-funded Science For Early Adolescence Teachers (Science FEAT) Program (Spiegel et al., 1995). As Paulette develops a theory of how children learn, she analyzes and describes her learning and her students' learning using a constructivist model (Glasersfeld, 1989; Tobin et al., 1990; Marzano, 1992; Tobin and Tippins, 1993; Brooks and Brooks, 1993; Appleton, 1997). Utilizing constructivism is a powerful way for all of us to learn.

We want to encourage all our students to learn. We need to remember that students must start with their current conceptions and build (and reconstruct) on them. As they realize that they can think analytically, a part of the world that may have been closed off to them opens up. Analytical thinking is challenging and stimulating. As Bruno tried to make sense of his data on the Doppler shift in his presentation to the class, he was obviously confused in his conceptions of frequency and amplitude, although he said that it was easy. I believe that he sensed that everything did not make sense probably during, and definitely after, his presentation to the class, especially when the students asked him questions and introduced conceptions that did not fit with his. After Bruno had a chance to reflect on his class presentation, he shared with the students on the course's web site how he realized he could do an experiment with his students to teach the frequency of a wave and the Doppler shift. In Bruno's suggested experiment as the student walks toward the rolling balls while catching them, he catches the balls more frequently than if he had stayed still (i.e. analogous to the blue shift). When he catches the balls while walking away from the rolling balls, he catches the balls less frequently than if he had remained
stationery (i.e. analogous to the red shift). Therefore, Bruno shared his understanding on frequency with the other co-learners in the classroom. I suspect that Bruno will never forget the Doppler effect and his understandings of frequency because he faced his misconceptions and figured out what makes sense and how he can test for it. He still needs to understand how to differentiate frequency and amplitude, but that will be another lesson. I suspect now that he understands frequency, amplitude will be much easier.

Conclusions

These results suggest that teacher-students can learn physical science when they utilize multiple opportunities to learn, including action experiments, textbook reading, dialogue both in class and on the world wide web, field experiences, and opportunities to innovate, utilizing everyday materials. Time will tell if the teacher-students incorporate a constructivist model for teaching physical science in their own elementary school classrooms, and if their students learn science when we teach science in this manner.

We need to help our students face that dissonance, that uncomfortable feeling, when everything does not make sense. We want our students to learn that if they conduct more action experiments, think deeply, using the language of science and confronting their misconceptions, they can learn to think analytically about physical science. Students will gain confidence in themselves, as evidenced in Paulette’s statements, as they experience this. The teacher-students will want to share their way of thinking with their students. It opens up a new way of seeing the world.

Note

1 I acknowledge the help and vision of Ms Elizabeth Williams for co-authoring the selection of the experiments in the curriculum that I used in the physical science course for elementary teachers. In addition, I thank Professor Kenneth Tobin for critically reviewing the manuscript for me.

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