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ABSTRACT

This paper discussed the use of structured observations as a research strategy in two recently completed studies that investigated students thought processes and behaviors in a microcomputer-based laboratory (MBL) environment and in other instrument-based laboratory environments. In the first study, students' behaviors and thought processes were investigated as they performed an acid-based neutralization. Eight students were divided into two groups and performed the same tasks but used different instruments. In the second study, students thought processes were investigated as they performed a series of acid-base titrations using either a microcomputer-interfaced pH probe, a stand alone pH meter, or a chemical indicator to detect changes in the pH of the chemical system. Fifteen students were divided among the groups. In both studies, the students were encouraged to think aloud as they were videotaped performing laboratory activities, and were sometimes asked to clarify and explain their expressed thoughts. The videotapes were then analyzed to determine how well the students' actions corresponded to their self-reported thought-processes. Structured observations recorded provide data about how students interact both with the instrumentation of the treatment and with the cognitive tasks of the treatment. (Author/MLB)

The Use of Videotape to Analyze the Correspondence between the Verbal Commentary of Students and Their Actions When Using Different Levels of Instrumentation During Laboratory Activities

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Problem Statement

In this paper we discuss the use of structured observations as a research strategy in two recently completed studies that investigated students thought processes and behaviors in a microcomputer-based laboratory (MBL) environment and in other instrument-based laboratory environments. Structured observations, as discussed by Krajcik, Simmons & Lunetta (1988), require the simultaneous videotaping of each observation or treatment session along with recording students' verbal commentary as they interact with an activity. The videotaped records capture the correspondence between students' observed actions and their verbal commentary about their predictions, explanations, observations, and procedural decisions. The videotape and audio tape records enabled us to compare how a student's actions and the instrument readings related to that student's verbalizations.

Laboratory activities represent complex task environments for students. During laboratory activities, students physically manipulate materials, perform procedures, and make decisions, observations, and explanations. This complexity makes a laboratory setting a difficult place to study learning, but structured observations may be an effective research tool because the researcher can simultaneously capture student's thoughts as expressed in verbal commentary, the student's actions as a result of those thoughts, and the physical manipulations and instrument readings that are part of the student's sensory input to the next series of thoughts.

In the studies reported here, students were encouraged to think aloud as they were videotaped performing laboratory activities, and they were sometimes asked to clarify and explain their expressed thoughts. The videotapes were then analyzed to determine how well the students' actions corresponded to their self-reported thought processes. Structured observations recorded in this manner provide a rich data set about how students interact both with the instrumentation of the treatment and with the cognitive tasks of the treatment.

Theoretical Perspective

Conceptual Framework

Because this paper reports on the application of the research technique of structured observations to the study of human cognition, we briefly review the theoretical bases used to support the claim that verbal data indicate thought processes which give insight into the cognitive structure of the individual verbalizing. Three models help support this claim: 1) a model of cognitive structure is needed to understand how learners organize their knowledge, 2) a model of cognition is needed to evaluate how learners' thought process operate during an activity, and 3) a model of concurrent verbalization is needed in order to have some confidence that students' verbalizations are indicative of their thought processes. Taken together, these models lend credence to the claim that students' cognitive structures and thought processes can be ascertained to some degree by interviews and think-aloud protocols.

A model of cognitive structure is provided by the generative learning model. The generative learning model indicates that students learn by building their own cognitive structures (Wittrock, 1986, 1978, 1974). The primary thesis of this model is that learners generate their own meaning from instruction based on their background, attitudes, abilities, and experience. Learners selectively attend to the flow of information, and their preconceptions determine the information to which attention is paid. The brain actively interprets this information and draws inferences based on its stored information. The newly generated meanings are then actively linked back into the learner's prior knowledge base. In sum, learning is viewed as a cyclical process, with new information being compared to prior knowledge and then being linked back into that knowledge base.

Osborne and Wittrock (1983) extended the model to the acquisition of scientific knowledge, and Osborne and Freyberg (1985) presented evidence that "children's science" plays a major role in helping or hindering the formation of appropriate concepts and concept linkages. In Osborne and Wittrock's elaboration of the generative learning model, students build sensible and coherent understandings of events and phenomena of the world from their point of view. These understandings can be referred to as conceptual structures (Osborne and Wittrock, 1983) or cognitive structures (West, Fensham, and Garrard, 1985). Throughout this paper, we will use the term cognitive structures. Because learners construct coherent understandings, words such as 'acid' and 'base' are labels for elaborated cognitive structures stored in the brain. West et. al. point out, however, that students' cognitive structures for these words are often quite different from the cognitive structures of scientists. These different cognitive structures that students bring to instruction are called alternative frameworks (Driver & Easley, 1978). Throughout this paper, we refer to students' cognitive structures that differ from the views of scientists as alternative conceptions. Linn et al. (1990) refer to these conceptions as intuitive conceptions; however, we prefer alternative conceptions to intuitive conceptions because learners actively construct these conceptions by synthesizing their experiences. Hence, they appear to be more than "intuitive."

West, Fensham, and Garrard (1985) have studied student learning in chemistry and have attempted to describe the cognitive structures developed by individual learners and by groups of learners. They claim that knowledge has two components: public knowledge and private understandings. Learning consists of taking the public knowledge presented by instruction and in textbooks and relating it to previous knowledge and experience to arrive at a private understanding of the knowledge that has been presented. They argue that public knowledge is definable but private understandings of that knowledge will vary with the individual learner.

In chemistry, West, Fensham, and Garrard (1985) argue that the two main types of public knowledge are propositions and algorithms. They define propositions as declarative statements which are definitional in nature (An acid has a pH less than 7.). Algorithms are defined as public knowledge of how to perform a process (neutralize an acid). The private understandings which result from the learner's acquisition of this public knowledge are concepts and skills. Concepts are a set of propositions that a person uses to infer meaning for a particular topic, such as pH. A concept will usually include both the public knowledge definitional propositions and all other knowledge, public and private, that a person relates to those propositions. A skill is considered to be the ability to perform a specified task. People who can perform a task are said to possess that skill; they may or may not use the 'book algorithm' to perform the task.

This cognitive structure can be affected by the addition of new knowledge bits or the creation of new relationships. Humans constantly change their cognitive structures (West, Fensham, and Garrard, 1985), and every observation potentially adds to some part of our cognitive structure. The two studies discussed in this paper investigated students' cognitive structure of acid-base chemistry by using thought processes to indicate what acid-base concepts were used by students to understand the titration activities.

The model of human cognition and of concurrent verbalization used in these studies was developed by Ericsson and Simon (1984), who argue that verbal data can indicate thought processes. Their model views cognition from an information processing perspective, and the term 'cognition' is applied to all stimuli, internal and external, processed by the memory. These stimuli are then subjected to cognitive processing, which Ericsson and Simon define as "a sequence of internal states successively transformed by a series of information processes" (page 11).

The information can be stored in, and accessed by, three main memories, all of which have different capacities and access characteristics. First, there are several sensory memories which store information for a very short time. Second, there is a short-term memory (STM) which has a limited storage capacity but can hold information for a longer period of time than the sensory memories. Third, the long-term memory (LTM) has a very large capacity and will hold information relatively permanently. However, the LTM has a slow access time and fixation rate (defined below) compared to the other memories.

Within this model, information flows in a definite pattern. A central processor controls the information to which an individual will attend and this information is stored in STM. While in STM, information is accessible for verbalization and further processing. Information can also be transferred from STM to LTM for permanent storage. Similarly, information stored in LTM can be transferred (retrieved) to STM, where it can be verbalized and/or reprocessed. An important assumption of this model is that only information in STM is available for verbal reports. This means that students' verbalizations reflect to some degree the contents of STM and provide clues to what information from LTM and/or the environment is being heeded.

If students do indeed learn by generating their own knowledge, then the activities that they engage in and their thought processes during the course of an activity become important. If, during the activity, students are actively engaged in retrieving concepts from long-term memory, in analyzing the activity in terms of their previous concepts, and in modifying and/or extending the propositions which define their science concepts, then it is possible that the information developed during the activity will be integrated in long-term memory with information about these concepts gained from classroom instruction, text readings, previous laboratory activities, and general knowledge. This integration should result in associating more propositions with each concept and in making more associations between concepts. These two activities would therefore lead to increased comprehension. These outcomes can best be assessed using the technique of structured observations because the videotape record allows the researcher to compare the students' behaviors with their verbal commentary.

Use of Instrumentation in Science Learning

In partial response to concern over students' difficulties in learning science, instrumentation, such as microcomputer-based laboratory (MBL) equipment and pH meters, might be used in the laboratory to enable students to deepen their concepts of such topics as acid-base chemistry. Several studies have reported that MBL apparently helps students develop better understanding of science concepts; however, it is important for educational researchers to investigate what students are thinking about when using these instruments to ascertain if students are indeed developing detailed, integrated science concepts (Linn, 1986).

Unfortunately, we know very little of what students think about when they are engaged in laboratory activities, and we know even less about students' observable behaviors and thought processes in a microcomputer-based laboratory environment. A number of science education researchers have claimed that MBL activities should help students engage in scientific procedures, including asking "What if?" questions (Tinker, 1981) which would indicate that students were actively engaged in thinking about the activity. Lunetta, Hofstein, and Giddings (1981) argue that very little is known about the learning outcomes that occur when students interact with a cognitive task in the environment of a laboratory activity. The method of semi-structured observations attempts to investigate the interaction between students' thoughts and their observed actions as they perform laboratory activities using microcomputer-based laboratories and other forms of instrumentation.

Several researchers have used quantitative measures to examine some of the learning outcomes which result from using MBL in classrooms (Brasell, 1987; Mokros & Tinker, 1987; Layman & Kirkpatrick, 1988; Lewis & Linn, 1989, Linn & Songer, 1988; Linn, Layman & Nachmias, 1987). Several studies have explored the affect of MBL on graphing skills and graph interpretation and have shown a positive impact (Mokros & Tinker, 1987; Layman & Kirkpatrick, 1988; Linn, Layman & Nachmias, 1987). Other studies have investigated the affect of MBL on the development of concepts. These studies indicate that MBL can have an influence on shaping conceptual development; however, the instruction in which it is embedded plays a critical role (Lewis & Linn, 1989, Linn & Songer, 1988; Linn, et al. 1990; Thornton, 1990). Brasell (1987) investigated in the direct impact of real-time graphing. She reported that high school physics students improved in their comprehension of distance and velocity graphs using an MBL unit with real-time graphing as opposed to either pencil-and-paper graphing or MBL with delayed graphing. These studies point to potential of MBL becoming a powerful tool in the science classroom. To date, studies have not explore the interrelationships between students' thought processes and behaviors as they performed the laboratory activities in the MBL environment.

The present paper describes the use of structured observations in two studies to analyze the correlations between the verbal commentary and behaviors that occur during a think-aloud, activity-oriented session. More specifically, the activity focused on the neutralization of acids and bases, using either a pH meter, a pH probe interfaced with a microcomputer, or the traditional colorimetric titration. More qualitative studies are needed to construct models of how students' behaviors when performing MBL activities correlate with their thought processes and to how these behaviors and thought processes affect their construction of chemical knowledge.

Use of Structured Observations

Design of the Studies

In the two studies described below, students were asked to think aloud as they performed laboratory activities using different levels of instrumentation. In each of these studies, students were told that we were interested in what they were thinking as they worked, and they were instructed to "talk aloud" and to "think aloud." during the activity They were prompted to do so throughout each session. A standard list of prompting comments was used as suggested by Larkin and Rainard (1984). Examples of these comments are "Can you tell me what you're thinking?", "Can you tell me what you're doing?", and "Please remember to think aloud "

Sometimes, however, probing questions had to be asked in order to encourage students to express their thoughts more clearly and to ascertain what background knowledge they were bringing to bear upon the problem. Examples of these probes are: "What do you think it means to 'neutralize the acid'?", and "What do you think (the graph) might mean?" In the first study, these types of probes were sometimes asked during the activity, but in the second study these probes were used after the activity was completed.

<u>Design of the First Study</u>. In the first study, students' behaviors and thought processes were investigated as they performed an acid-base neutralization. Eight students were divided into two groups and performed the same tasks but used different instruments. One group used a stand-alone pH meter, and the other group used a microcomputer interfaced with a pH meter. Students performed the activity individually, and their actions and verbal commentary were recorded on videotape and were subsequently analyzed to correlate their behaviors with their verbalizations.

In both observation groups the students had two tasks: to calibrate the instrument using known buffer solutions and to neutralize an acid. For the neutralization procedure students were simply instructed to "neutralize the acid." All appropriate solutions were labelled and available; however, students were not given specific directions on how to select and use those materials in order to neutralize the acid. It was decided that nonspecific instructions would make greater cognitive demands and provide the opportunity for more verbalizations, thereby giving a more complete picture of the cognitive processes involved. However, specific, written instructions were given for the calibration procedure, and all the solutions needed to complete the calibration task were labelled. This was done because students might not be as familiar with the instrument calibration task as with the neutralization task.

Students wore a microphone and were videotaped as they worked through the each session, providing as full a data set as possible. The videotaping focused primarily on close-ups of their actions and on close-ups of the pH meter readings or of the graphs generated by the computer which were displayed on the computer's monitor. The videotapes were transcribed, and the resulting protocols were coded using coding categories, as suggested by Ericsson and Simon (1984), and analyzed by counting frequencies in each category.

Design of the Second Study. Students' thought processes were investigated as they performed a series of acid-base titrations using either a microcomputer-interfaced pH probe, a stand-alone pH meter, or a chemical indicator to detect changes in the pH of the chemical system. Fifteen students were divided among the groups. As the students performed the titrations, their verbal commentary was recorded and the readings on their instruments were videotaped. Unfortunately, the lighting was not sufficient for the video portion of the tape, but the audio portion was used for a comparison.

Students in this study were given an individual orientation session in which they practiced thinking aloud and using their instrument. The researcher modelled the appropriate instrumental technique and also modelled thinking aloud by giving examples of verbalizations of thoughts (like "I remember that acids are sour"), of emotions (like "I don't understand this, and I feel frustrated"), and of thinking processes (like "Now I think I'll add some base"). Then the student practiced using the instrument and verbalizing, and the researcher gave feedback when the verbalizing was adequate and reminded the student to think aloud whenever a pause lasted longer than three or four seconds. If verbalization was inadequate, the student was told that he or she needed to verbalize more and was given encouragement to do so. At the end of the titration, students were given more encouragement to verbalize every thought they had, and students were asked how they felt about doing this activity.

Data Analysis

The videotapes and audio tapes of both studies were transcribed, and the resulting protocols were coded and analyzed by frequency counting. Coding categories were derived from the data.

Description of the Coding Categories. In the first study, students' transcripts were reviewed and coding categories were developed from the patterns perceived in the verbalizations. The statements were coded as belonging to one of five categories: procedural statements, analytical statements, emotional statements, statements revealing an inadequate concept, and statements expressing an adequate concept. Some statements were complex, and these statements were therefore assigned codes in two or more categories. Frequency counts of these categories were taken for each student. Table 1 contains a summary of the coding categories used in this study. Table 2 contains examples that illustrate the coding categories.

Table 1

Coding Categories for the Analysis of Think-Aloud Protocols in Study #1

1. **Procedural statements referring to**
   a. Reading or questioning directions.
   b. Performing an action.
   c. Stating a goal.
   d. Deciding what to do next or admitting not knowing what to do next.

2. **Analytical statements referring to**
   a. Observing, interpreting, or explaining events or text.
   b. Understanding or not understanding observations or text.
   c. Hypothesizing about concepts.
   d. Recalling pertinent subject matter knowledge.

3. **Emotional statements referring to**
   a. Puzzlement, frustration, or satisfaction.

4. **Statements expressing inadequate understandings of**
   a. pH, acids, bases, neutralization or buffers.

5. **Statements expressing adequate understandings of**
   a. pH, acids, bases, neutralization or buffers.

Table 2

Examples of the Coding Categories for Study #1

1. **Procedural statements.**
   a. "Now I'm placing the electrodes in the pH 4."
   b. "Turn to standby and plug in."
   c. "Are you sure this is the right way to calibrate?"

2. **Analytical statements.**
   a. "I'm wondering how come every time I add one or the other it's always overshooting."
   b. "As it (the pH meter needle) gets higher the line goes up."
   c. "So the NaOH, I would think, um, brings all the numbers up higher."

3. **Emotional statements.**
   a. "I'm confused right now."
   b. "I'm thinking about how much it would cost to replace this meter if I was to just smash it or something."
   c. "There you are."

4. **Inadequate understanding statements.**
   a. "What is a titration?"
   b. "So this would be sort of like a peroxide, I guess, since it has hydrogen in it."
   c. "Now do the second experiment, which is adding pH 7 in the distilled water."

5. **Adequate understanding statements.**
   a. "Well, pH of 7 is like right in the middle, and I think that's where the neutralization occurs."
   b. "....the lower side of the scale is for acid and the upper side is for base..."
   c. "The hydrogen chloride, or whatever it is, is acid, isn't it?"

In the second study, the data were categorized slightly differently because the task demands were different. Because students performed three titrations of adding a base to three different acids, we found it necessary to add an observational coding category. In addition it was difficult to reliably code separate conceptual and analytical statements because students would often combine them in one sentence, so the two categories were collapsed into one category. The students' statements were categorized as procedural statements, observational statements, or conceptual/analytical statements. Statements were categorized as procedural if they referred to the titration procedure, as observational if they referred to the changes in the acid-base systems which the students could see, and as conceptual/analytical if the statements referred to the processes of interpreting, analyzing, and predicting in which the students engaged as they performed the titrations. Table 3 summarizes the coding categories used in the second study. Table 4 contains examples that illustrate the categories.

Table 3

Coding Categories for the Analysis of Think-Aloud Protocols in Study #2

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1. Procedural statements referring to
   a. Adding milliliters.
   b. Stirring or swirling the solution.
   c. Recording the data.

2. Observational statements referring to
   a. Color change of the solution.
   b. pH meter needle movement.
   c. Values of pH read from the meter or microcomputer screen.
   d. The shape of the graph on the computer screen.
   e. How fast or slow change occurs within the present activity.
   f. Changes in shape, color, or motion within the present activity.
   g. Inability to see anything happening.

3. Conceptual/Analytical statements referring to
   a. Concepts recalled from long-term memory.
   b. Speculation as to why an event occurs.
   c. Comparing present observations with past activities
   d. Predictions as to what might happen next.
   e. Statements that the student is not thinking of anything.

4. Miscellaneous statements referring to
   a. Linking words and interjections such as OK, well ,so, wait a minute.
   b. Emotional words such as wow, whew, crazy, boring, and wild.
   c. Questions and/or comments directed to the observer such as look at this, can I do this without goggles, and did you see what happened.

Table 4

Examples of the Coding Categories for Study #2

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1. **Procedural statements.**
   a. "We're going down to 18."
   b. "Stir this up again."
   c. "20 on the keyboard and enter."

2. **Observational statements.**
   a. "See a pink color when you pour."
   b. "10.0 pH units at 24."
   c. "Needle sure enough moved up fast that time."
   d. "And it looks like it's going upwards, it's climbing now."
   e. "Because the pH changes so slowly from when I put in about 22 milliliters it changed very quick."
   f. "Straight line. Doing what it did in the beginning."

3. **Conceptual/analytical statements .**
   a. "I think this acid is stronger than the one we used last time."
   b. "After a certain point the colors weren't like going to change much no matter how much NaOH you add to the acid."
   c. "The graph looks different than last time."
   d. "I wonder what happens if you just. . . . put NaOH in there. . . . and take the probe and put it in there and see if the needle goes up."
   e. "I'm not thinking anything. I don't think that much."

4. **Miscellaneous emotional statements and statements directed to the researcher.**
   a. "Whoa."
   b. "It drove me crazy yesterday."
   c. "Now, is this, is this the only thing that we going to do?"

Results and Analysis

This videotaping/recording technique combined with these coding categories for the verbal data allowed us to describe in some detail what students in an instrumentation environment. For example, students in both studies spent a major portion of their time on procedural matters and relatively little time in observing, drawing conclusions, or making inferences based on the data that they were accumulating.

First Study. In the first study, the audio tapes enabled us to tabulate the frequencies of statements within each coding category. Table 5 clearly shows that students verbalized a substantial number of procedural statements, and relatively few analytical or conceptual statements which could provide evidence of their ability to relate the physical manipulations of the activity to their knowledge of the subject.

Table 5

Average Frequency of Statements Per Coding Category by Group for Study #1

	pH Meter Group	Microcomputer Group
Procedural	444*	573
Analytical	191	73
Emotional	32	16
Inadequate understanding	11	32
Adequate understanding	43	17

*Number of statements made by each group in each category.

The videotapes facilitated analysis of students' actions in conjunction with their verbal commentary, and allowed us to identify behaviors which contributed to this involvement with procedures. The videotape record revealed that four behaviors were observed in connection with verbal commentary concerned with procedures.

First, the students ignored what they didn't understand. For example, some students skipped the instruction to check the temperature setting on the pH meter because they couldn't find the temperature knob. One student said "I'm not sure where the temperature dial is, but uh I'll just have to skip."

Second, students forgot several steps in the written procedure. For example, students would prepare a beaker of solution but forget to place the pH meter electrode in the solution. One student in the pH meter group failed to adjust the pH setting on the meter despite explicit instructions to do so. Two other students correctly adjusted the meter reading; another student spent considerable time attempting to adjust the meter before realizing that the meter was set to standby and could not respond. These two behaviors would occur often at the beginning of the activity, but they would also occur throughout the activity.

Third, if a student became confused, the general tendency was to stop and start all over again, and fourth, some students were unable to recognize when a task had been completed. For example, several students finished both tasks and then started over again because they did not recognize that they were finished. In the microcomputer group, students had particular difficulty in recognizing when the calibration task was completed. Each student would finish the calibration, hesitate, reread the directions, and then decide to go back and redo the calibration. One student performed the calibration, didn't realize that the task was completed, and performed the calibration again. Later in the observation the student went back and calibrated a third time. Two students performed the calibration incorrectly the first time, did the calibration correctly the second time, and started to neutralize the acid. They could not decide on a goal for the neutralization so they repeated the calibration for a third time. When asked why they were doing the procedure, they replied "to calibrate the probe", "to get more data."

The videotapes also revealed several instances when students in the microcomputer group failed to see the pH meter interfaced to the microcomputer as a connected whole. One student calibrated the pH probe without realizing that the computer program was on the wrong selection. The same student, making a second attempt at calibration, typed in the correct pH values on the computer but left the electrode lying on the counter top. This student also made no attempt to adjust the pH meter reading; he/she simply accepted whatever value was displayed.

Second Study. In the second study, the audio portion of the tape was used to code the verbal commentary and to compare the sequences of behaviors across treatment groups. This methodology allowed us to analyze how each group interacted with a specific technology.

Frequencies across Groups. After coding the think-aloud protocols, the frequencies of each category were computed and group averages were compared across treatment sessions and across groups. The frequency of procedural statements decreased within a group across treatment sessions. This was expected because we had predicted that the number of procedural statements would decrease as the students became more familiar with the routine of titration. We had also predicted that the frequency of analytical statements would increase as students became more familiar with the titration routine, but we found that the frequency of conceptual/analytical statements, as well as observational statements, decreased for the second treatment session and then rose in the third treatment session. This increase was possibly due to the use of phosphoric acid in that session because phosphoric acid ionizes in several stages and therefore exhibits a slightly different behavior than the previous two acids.

Across groups, the microcomputer group consistently had the highest frequency of procedural statements, which might be because the microcomputer group students were required to enter the milliliters added into the computer and the other groups were required to write down the number of milliliters added and their observations of color changes (chemical indicator group) or of pH values (pH meter group). It is possible that the act of entering data was sufficiently different from writing that the microcomputer students verbalized this step and the other students did not. For example, in treatment sequence 2 the following sequence occurs (#0301.JC, page 2, the underlined statements are procedural): [1]

<u>Swirl that around.</u>
<u>Put in 8.</u>
It is going to 4.11
<u>Return.</u>

Compare that sequence to one from the chemical indicator group (#0110.DH, page 2, the underlined statements are procedural):

<u>Stir this up again.</u>
OK.
Bubbles.
This is getting boring.
Clear, see some bubbles.
<u>16.</u>

[1]The first two digits of the student's number give the treatment group, and the last two digits are sequential for ordering purposes. The letters serve to further identify each subject. Therefore this student is in the third treatment group and is the first student in the whole sample.

There.

Also compare these sequences to one from the pH meter group (#0209.DR, page 3, the underlined statements are procedural):

> And I am going to stir this again.
> See something changing.
> Oh, hum, it is moving up to 4.1 pH unit now.
> Wonder why it won't start at 1 or a 0 you know.
> The needle, why does it start at 4.00?
> Hum, I don't know why.
> Go down 6 now.

These three sequences all involved stirring, making observations and inferences, and then adding more NaOH. However, only the microcomputer group verbalized the act of recording the data by saying the word "Return." Again, pressing "Return" on the computer is not as automatic as writing down the pH.

The microcomputer group also had the lowest frequency of conceptual/analytical statements. However, it is possible that these statements, although fewer in number are more meaningful. Consider the following sequence from the microcomputer group (#0302.JC, treatment sequence 3, page 2, conceptual/analytical sequences are underlined):

> 22.
> Hum. . . .
> It is different from other graphs we did.
> This is going up
> An increase in the pH a lot slower than the other graphs we did.
> Let's turn this toward me.
> That's 24.
> Make sure . . . .
> This is totally . . . .
> Now at 26.
> Almost turned to water.
> Maybe by the time the experiment is done I could probably drink this stuff.
> 28.

This sequence indicates that the student compares the graph being formed with the graphs produced in previous activities. This comparison is possible because of the real-time capability of MBL. Also, notice that the student makes a prediction as to the probable nature of the products of the reaction. Compare that sequence to the following one from the pH meter group (#0209.DR, treatment sequence 3, page 4, conceptual/analytical sequences are underlined):

It just keep going on down again.
Umph, wonder what happened there.
I had 2 point 0,
Guess this still phosphoric acid that's in there.
Still, I think that's still more phosphoric acid in here now.
Just 2 milliliters won't do any good
So I guess I got to let it go 2 more down now
To four or something.

This sequence mainly involves an assessment of the condition of the phosphoric acid and a decision to proceed with adding the NaOH. NaOH is the base used in all the titrations, and the student is judging whether the phosphoric acid has been completely titrated or whether more base should be added. The whole sequence is more tentative than the microcomputer sequence.

A comparison of these two segments indicate that students in the MBL environment tended to focus their commentary on more conceptual issues. Apparently, the graphic nature of MBL and the real-time graphing capability fostered this level of conceptualization.

The pH meter group consistently had the highest frequency of observational statements. This might be because the students focused on two phenomena: the movement of the needle and the pH value on the scale. For example, consider the following sequence from the pH meter group (#0207.CS, treatment sequence 3, page 2, observational statements are underlined):

Add some more.
It is gone way down on me again 10.1.
At 42.
Hum, . . . 10.7.
44.
Comes up fast.
Sometimes it is slow and other times . . . .
Looks like it is going to stay at 11.
46.
2 more.
It moved a slight bit to 11.2.
At 48.
2 more for our last two.
The last reading is 11.4.

These observational statements report both the movement of the pH meter needle and the pH values on the scale to which the needle points. Therefore it is not surprising that this group had a higher average frequency of observational data. Table 5 presents a breakdown of the frequencies of statements by treatment session and by category.

Table 6

Average Frequency of Statements Per Coding Category by Treatment Session and by Group for Study #2

	Procedural			Observational			Conceptual/Analytical		
Treatment	1	2	3	1	2	3	1	2	3
Chemical Indicator Group									
	40	29	23	41	28	35	32	19	14
pH Meter Group									
	42	34	34	74	58	62	48	26	40
Microcomputer Group									
	53	42	36	44	26	33	20	10	15

Pattern of verbal commentary. The protocols were analyzed by examining the sequences in which the coded categories occurred during the think aloud. No pattern was detected when each coded statement was counted separately because a pattern of procedure-observation-conceptual would then be different from a pattern of procedure-procedure-observation-conceptual although the two patterns would actually be very similar. Therefore only the sequencing of categories was followed, and no attempt was made to count the specific number of statements in each category. Of the 42 patterns that were analyzed, 43% of them were the sequence $[\text{procedure-observation}]_n$-conceptual/analytical. In this sequence the procedure-observation segment might be repeated n times before being followed by a conceptual/analytical segment. Over the entire sample of students, 29% used this sequence for every treatment session.

<u>Focus of student's observation</u>. The structured observation technique was most helpful in determining the focus of the student's observations. Each protocol was analyzed to determine what was the focus of the student's observations during each of the three titrations. The focus was determined by determining the object of each observational statement. A definite and different pattern developed for each treatment group. For the first two titrations all the students in the chemical indicator group focused on color, but some of them also focused on bubbles, shadows in the beaker, and characteristics of the liquid, such as "oiliness." In the third titration, all except one member of the group focused only on color.

The following sequences from a student in the chemical indicator group illustrate this shift in focus (#0103.CP, treatment 2, pages 2-3):

Four.
It doesn't smell that good.
Six.
Trying to look for the bubbles and all of that stuff.
Six milliliters,
Clear.
Still clear.
Looks the same.
10.
Still clear, nothing at all.
12.

R: What are you thinking?

We are getting bubbles inside the solution.
You know, like we had the bubbles last time.
14. Think I saw a little pink change.
There, I guess between 12 and 14 is when the solution begins to
react.
16. A little bit more pink.
Clear.
And seems solution turns bright pink to clear.

In the third treatment sequence this same student focused exclusively on the color (#0103.CP, treatment 3, page 3):

Four.
It is still the same.
No change.

Four to eight, it's up to six.
Shucks.
OK, no change.
Same color.
OK, adding two more.
OK, I don't see any change in it.
All right.
It really is . . . .
Since we're using lesser amount of acid, the color change should
be about
10 I guess.
Close to 10 I think.
Eight milliliters.
No change.
OK, 10 now.

R: What are you thinking?

I think the color was light red, but it is more like an orangish color.
You think it is?
OK. two milliliters.
Gosh.
So, I guess the color was light orange.

For the first two titrations in the pH meter group, all students focused on the movement of the pH meter needle and/or on the pH value, but two students also focused on the thickness of the solution, bubbles, and the tip of the pH probe. By the third titration, all members of the group focused on the movement of the pH meter needle and/or the pH value. Most of the students focused on both the pH meter needle and on the pH values to which the needle was pointing.

The following sequences from a student in the pH meter group illustrate this shift in focus. First, the student focuses on bubbles, needle movement, and pH values (#0207.CS, treatment 2, pages 2-3):

Down two more.
And now it is six.
The meter is 4.3.
I think this acid is stronger than the one we used last time.
Add some more.
Going down to eight.
Something is bubbling at the bottom.
It moved to 4.5
Going to add some more.
And it move to 4.5.
Add some more.
Now up to 4.8, that is 12.
Down 2 more.

That is 5.1.
14.
Two more.
That is 5.1.
14.
Two more.
Wonder if you shake it the bubbles will go away?

By the third treatment sequence, the student focuses only on the pH meter needle and the pH values (#0207.CS, page 2):

Down to 18.
2 point 4.
20.
I'm still trying to go one at a time.
Looks like I'm going to get to 5.5
Two more.
Down 22.
It is jumping back and forth on me a little bit.
It is at 6.1.
22.
Down two more.
24.
We got 6.5.
Add two more.
6.5, oh no, 6.6.
Add two more.
6.8.

The microcomputer group focused on the shape of the graph in the three titrations. Two of the students in the group did not verbalize enough observations to ascertain their focus. Two students followed the vertical rise of the graph very closely, paying particular attention to the fact that on a color monitor these vertical lines are multicolored. In the first and second titrations, pH values, which were also displayed on the screen, were also a focus of observation for a student.

The following sequence illustrates the typical focus of a microcomputer group titration (#0312.NM, treatment sequence 3, page 3):

Swirl it around.
24 into the computer.
Return.
It's got an S shape.

More compact S than the other ones.
Same shape
but more compact.
And there is no multi-colored line.
. . . .
But there is
. . . .
Line goes almost straight up.
And it is multi-colored.
That could be it,
Point where it is neutral.
pH 6.57.
26 into the computer.
Return.
Still continue into an S shape.
28 now.
Right there.
Swirl it around.
pH goes up and then it comes back down.
Enter 28 into the computer.
Return.
Still continues a S with a slight upward swing.

The observational statements were very helpful in determining the focus of the student's observations. Ericsson and Simon's model of cognition states that verbal reports of observations indicate what information is being attended to and processed in short-term memory. Therefore the observational statements were an index of what phenomena were being attended to by the student.

The chemical indicator group sometimes attended to irrelevant phenomena. Sometimes the students seemed not to know what to observe, so they observed everything. These students also had no immediate, visual method of evaluating the progress of the titration. There were periods of time when nothing apparently happened because the color change did not come until neutralization, and therefore some of the students decided that no reaction occurred until the color change occurred. There were other periods in which the color came and faded again. One or two students did guess that this was due to a localized concentration of base because they noticed that the color faded upon stirring.

The pH meter group had a more difficult problem with respect to their use of short-term memory. These students were aware of two things: the movement of the meter needle and the pH value. Therefore their observational statements indicate that they were mentally juggling three variables: pH value, needle movement, and the number of milliliters of base added. This burden may have exceeded their memory capacity, and prevented them from speculating more about the reasons for this behavior.

The microcomputer group on the other hand had a relatively low demand placed upon their short-term memory because the microcomputer displayed the graph as it was being formed. Sometimes students would delay entering the data into the computer in order to predict whether the line would go up or not. After entering the data the students would then study the graph and decide if it was going to resemble the graphs of other acids. In a real sense, the computer seems to be functioning as an auxiliary memory (Linn & Songer, 1988), displaying a visual record of the titration for the student to reference at any time.

The microcomputer group also had a very narrow focus. The students focused almost entirely on the shape of the graph, particularly the region where the graph begins to rise steeply. According to Ericsson and Simon's model of cognition, this focus on only one piece of information, i.e. the shape of the graph, probably did not represent a cognitive overload for the students' short-term memory. Therefore more of their short-term memory was available for information processing and retrieval.

The microcomputer group had available three kinds of information: the volume of base added, the pH value of the solution after each addition of base, and the on-screen graph which was constantly formed during the titration. This is an amount of information similar to the amount of information possessed by the pH group; however, the microcomputer group's information was not transient. Therefore, the microcomputer students did not need to attempt to store in memory any of the information to which they were attending. All of the information collected in the titration was displayed in the graph at all times.

It is reasonable to speculate that the on-screen graph enabled the microcomputer students to focus their thoughts on what was happening and why it was happening rather than trying to remember what had happened and simultaneously trying to think about why it had happened. The manner in which the computer presented the information possibly allowed the computer to function as an auxiliary memory device, as suggested by Linn & Songer (1988). By maintaining the graph as a constant reference for the student, the computer allowed the student to use his or her short-term memory to make predictions or construct possible explanations for the graph. Therefore, students would have been more actively engaged in accessing their long term memory, and cognitive restructuring should have occurred which should have led to a more detailed understanding of the titration.

Educational Significance of the Methodology

The videotape and audiotape record enabled us to examine how well the students' verbal commentary agreed with their actual behaviors while using MBL or other technologies. At times students' comments were found to be incongruent with their actions, and at other times students' verbal commentary enabled us to ascertain the focus of their attention while they were performing the physical manipulations of the laboratory. The videotapes and audiotapes also enabled us to examine students' thought processes, as indicated by their verbal commentary, in order to provide some insight into the different types of thoughts which were heeded in short-term memory.

The coding categories proved to be a powerful method of analyzing verbal data for patterns. In the first study, these coding categories allowed us to identify a high percentage of procedural verbalizations, and the videotape enabled us to identify four behaviors which may have contributed to the students' high frequency of procedural verbalizations. Without the videotape record of these sessions, such a correspondence would have been difficult enough to uncover, let alone substantiate with convincing evidence. In the second study, the coding categories allowed us to examine the sequence and patterning of the verbalizations to uncover a common pattern, [procedure-observation]$_n$-conceptual/analytical, used in nearly half of the protocols. Again, this correspondence might not have been observed without this methodology.

In summary, videotaping and audiotaping think-aloud treatments and developing coding categories for the verbal data seem to be a powerful way of analyzing the interactions between students' thought processes and their observable actions. This technique allowed us to gain tentative evidence for why MBL may be a powerful instructional tool. The verbal commentary of students using the MBL indicates that these students attended to features that were more conceptually demanding. The real-time graphing capability of MBL served as an auxiliary memory device for students.

Structural observation may also play a central role in designing instruction. Using the technique, we can modify the instructional component, and observe in students pattern of verbal commentary and behavior is modified toward conceptually demanding activities.

Bibliography

Brasell, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. Journal of Research in Science Teaching, 24, 385-395.

Driver, R. & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 61-84.

Ericsson, K.A. & Simon, H.A. (1984). Protocol Analysis: Verbal reports as data. Cambridge, Mass.: The MIT Press.

Krajcik, J.S., Simmons, P.E., & Lunetta, V.N. (1988). A research strategy of the dynamic study of students' concepts and problem solving strategies using science software. Journal of Research in Science Teaching, 25, 147-155.

Mokros, J.R. & Tinker, R.F. (1987). The impact of microcomputer-based labs on children's ability to interpret graphs. Journal of Research in Science Teaching, 24, 369-383.

Larkin, J.H. (1981). Cognition of learning physics. American Journal of Physics, 49, 534-541.

Layman, J.W. and Kirkpatrick, D. (March,1987). Student Acquisition of Graph Features Application Skills and Graph Problem Solving Skills as Assessed by a Lightest Laboratory Practicum. Paper presented at the annual meeting of the American Educational Research Association, Washington, DC.

Lewis, E. L. & Linn, M. C. (April, 1989). Heat energy and temperature concepts of adolescents and experts: Implications for Curricular Improvement. Paper presented at the sixty-second conference of the National Association for Research in Science Teaching, San Francisco.

Linn, M. C., Layman, J. W. & Nachmias, R. (1987). Cognitive Consequences of Microcomputer-Based Laboratories: Graphing Skills Development. Contemporary Educational Psychology, 12, 244-253.

Linn, M. C. (1986). Computer as lab partner project. Teaching Thinking and Problem Solving, May/June. Hillsdale, NJ: Lawrence Erlbaum Associates.

Linn, M.C. & Songer, N.B. (1988, April). Cognitive research and instruction: Incorporating technology into the science curriculum. Paper presented at the American Educational Research Association meeting, New Orleans.

Lunetta, V.N., Hofstein, A. & Giddings, G. (1981). Evaluating science laboratory skills. The Science Teacher, January, 22-25.

Osborne, R.J. & Freyberg, P. (1985). Learning in Science: The implications of children's science. Auckland, New Zealand: Heinemann.

Osborne, R.J. & Wittrock, M.C. (1983). Learning science: A generative process. Science Education, 67, 489-508.

Tinker, R.F. (1981). Microcomputers in the teaching lab. The Physics Teacher, February, 1981, 94-105.

West, L.H., Fensham, P.J., & Garrard, J.E. (1985). Describing the cognitive structures of learners following instruction in chemistry. In L.H.T. West and A.L. Pines (Eds.), Cognitive structure and conceptual change (pp. 29-49). Orlando, FL: Academic Press.

Wittrock, M.C. (1986). Student thought processes. In M.C. Wittrock (Ed.), Handbook of Research on Teaching (3rd ed., pp. 297-314). New York: Macmillan.

Wittrock, M.C. (1978). The cognitive movement in instruction. Educational Psychologist, 13, 15-30.

Wittrock, M.C. (1974). Learning as a generative process. Educational Psychologist, 11, 87-95.