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Paper Title: Microcomputer Based Labs and their Influence upon Students' Conceptions of Light

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This study focuses upon the efforts of a third grade teacher and her students as they worked over an eight week period through a set of science activities written for use in conjunction with a light sensing probe. Analyses of videotapes of classroom sessions, samples of students' work, interviews with the teacher, and research field notes have led to a set of assertions about the role that the MBL technology played in the students' conceptions of light. As each of these assertions are presented, samples of classroom incidents will be offered as supporting evidence for these claims. Because of the naturalistic methodology used in this research, we must be cautious when trying to extend our findings to other situations (Borg and Gall, 1989). Nevertheless, there seem to be sufficient reasons to pursue further efforts at increasing the availability of MBL technologies in our elementary schools.

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Microcomputer Based Labs and their Influence upon Students' Conceptions of Light

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INTRODUCTION

The purpose of this paper is to communicate some of the findings from our investigations of elementary school students and their teachers as they worked with microcomputer based labs (MBLs). This study is drawn from a three year curriculum research and development project in which we explored the feasibility of extending MBL technologies from their current place in colleges and secondary schools into the realm of the elementary classroom. We have grown to appreciate the immense potential of MBLs as tools to enhance children's opportunities to investigate and better understand the natural world. While recognizing the multitude of barriers to widespread adoption of this technology (i.e., teacher training, computer availability, and equipment costs) there is growing evidence that suggests that the learning gains possible with the appropriate application of MBLs makes these tools justifiable additions to elementary school children's science experiences.

This study focuses upon the efforts of a third grade teacher and her students as they worked over an eight week period through a set of science activities written for use in conjunction with a light sensing probe. Analyses of videotapes of classroom sessions, samples of students' work, interviews with the teacher, and research field notes have led to a set of assertions about the role that the MBL technology played in the students' conceptions of light. As each of these assertions are presented, samples of classroom incidents will be offered as supporting evidence for these claims. Because of the naturalistic methodology used in this research, we must be cautious when trying to extend our findings to other situations (Borg and Gall, 1989). Nevertheless, there seem to be sufficient reasons to pursue further efforts at increasing the availability of MBL technologies in our elementary schools.

BACKGROUND

Microcomputer based laboratories

The term microcomputer based laboratories, or MBLs, refers to the class of technology which consists of a device called a probe used to collect data that a computer then processes and displays as a graph on the computer screen. MBLs have been found to be effective components of post-elementary science curricula for several reasons: students are active participants in scientific investigations; MBLs reinforce students' understandings through multiple learning modalities; MBLs link concrete experiences and observations with virtually instantaneous graphical displays of the data; and MBLs can accelerate the learning of science concepts (e.g., Mokros & Tinker, 1987; Woerner, Rivers & Vockell, 1991; Brasell, 1987; Barrow & Padilla, 1991; Stuessy & Rowland, 1989). Much of the research on MBLs has involved the use of distance/velocity probes and temperature probes; this may be the first study reporting about the use of a light sensing probe.

Conceptions of light

The behavior of light and its relationship to vision is a topic that has been a source of intrigue and speculation for thousands of years. A historical examination of conceptions of light should not be mistaken as an indication that I feel that children's conceptional development of light recapitulates the evolution of human thought on the topic; the parallels simply informs discussion of children's ideas without providing us with reliable predictive abilities.

Feher (1986) traced the history of theories about light and the following summary draws heavily from her paper. Feher contrasts multiple theories of vision espoused by the ancient Greeks. One theory, championed by Euclid and Plato, was that a person is able to see an object, such as a tree, because the eye projects visual rays that touch the object, thus allowing the tree to be perceived. These emissionists likened the ability to observe an object with the eyes to how we are able to detect the temperature of an object. In both instances, the body reaches out and contacts the object, thus allowing it to be sensed. In contrast, supporters of the intromission theory such as Lucretius believed that a miniature of the object travelled across space and when this eidolon entered the eye, the person saw the object. Presumably an intromissionist would explain the fact that a more distant object seems smaller to be a consequence of an eidolon that became reduced in size as it was transmitted.

The third theory that some ancient Greeks, including Aristotle, found sensible involved a compromise of the prior two theories. In this case, an emission by the eye and some representation of the tree meet resulting in the tree being seen. Feher (1986) points out that none of these three theories invokes the role of light in the ability to see, only the objects and the eyes. The Arabs in the Middle Ages incorporated light into the process of vision, but still borrowed from the intromissionist theory. This group claimed that light strikes an object which provokes the object into releasing the eidola. The role of light was to cause objects to transmit images of themselves. We can infer how the Arab School would explain why we are unable to see a tree on a dark night: without any light, no eidola are tossed about.

Kepler's theory of vision is the version that has received the endorsement of scientists for nearly four hundred years. According to this theory, light from a source strikes our tree and some of the light reflected off of the tree enters our eye. Our brain then processes the varying intensities and frequencies of the light, and we recognize the object. Kepler defined the behavior of light, leaving the process of mental perception to the neurobiologists. Nevertheless, this theory of light is the one that is considered the conception that we would like children to know.

Interviews of children have revealed conceptions that match those from scientific history, although there are many ideas that students have that are not ascribable to any historical roots. One example was identified by Guesne (1985) through her interviews of ten to fourteen year olds. Some children conceive of light as a fluid that surrounds all objects, much as water surrounds everything that swims within a pool. Children who hold to this conception of a "bath of light" make no effort to describe the transmission among eyes, objects, and light sources. Another intriguing theory of vision described by Osborne (1990) and Harlen (1987) differs from the Arab School theory in the agent activated by light. Some children suggest that light first travels to the eye which then becomes capable of seeing the object. This brings us to a discussion of how children represent light and vision.

As part of their curriculum research and development efforts, Osborne and his colleagues (Osborne, Black, Smith & Meadows, 1990) investigated the ways in which children showed how light, an object, and an observer interact. When asked to draw a picture that shows how a person is able to see an object, children used a variety of representations. Some depicted the light entering a room in a way similar to Guesne's "bath of light" without revealing how this gush of light enabled an individual to see. Other children represented light and vision with particles, either as a series of small ovals between an object and the eyes of the observer, or as a sequence of dashes. In most cases, although the proportion that did so became progressively greater with older students, children did not show any directionality in the movement of the particles. Another way of representing light by children was as a beam that resembles a wide stream rather than the discrete lines commonly seen in the ray diagrams in the optics chapters of physics textbooks.

Osborne et al. (1990) classified children's conceptions of vision into several categories. One category was that they were able to see by simply using their eyes. Some children will indicate that light is somehow necessary to see, but do not try to explain how light is important, apparently comfortable with the knowledge that the light is important. Eaton, Sheldon & Anderson (1986) found this to be the most common misconception among the middle school students with whom they worked. Another category of student descriptions involves what Osborne et al. (1990) referred to as a single link explanation. In these explanations, students acknowledge and identify connections between object and observer, but omit any involvement of a light source This is reminiscent of the three Greek theories described earlier. The last category involves explanations with dual links. Students with these types of explanations include a role for light in their explanations of how they are able to see an object. Any drawing made by a student that involves light, objects and eyes fall into this category. Therefore, explanations akin to the Arab School's eidola idea would be grouped here.

The representations that children make about vision are heavily context dependent. Osborne et al. (1990) presented some rather striking examples of students' drawings that show how the way in which a child explains vision often depends upon what situation is being depicted. For example, when was asked to show how light from a candle or flashlight could be seen, children show movement from the light source to the eye. However, these same children, when asked to draw how they are able to see a book, employ an active model of vision in which they show lines emitting from the eye and reaching out to the object. (Incidentally, a similar tendency was detected during a lesson with preservice elementary school teachers in a science methods course. When asked to sketch a picture that showed how they were able to see an object in a mirror, most of the students showed lines with arrows moving from the picture to the mirror and another set of lines moving from the eyes to the mirror so that the image was seen when the beams met.)

METHODS

The school where this study was conducted is located in an urban district in the greater Boston area. The third grade teacher, Ms. Vasenda*, had twenty years of teaching experience in this neighborhood school and personally knew all of the students' parents and many of their siblings. Of the twenty-three students, thirteen were girls. The students represented a mix of ethnic backgrounds and academic achievement with six of the students regularly receiving resource room help. Cooperative learning strategies had been used all year, so by the time of this study (January through March) the students were accustomed to working in pairs or threesomes. Ms. Vasenda reported that she taught science for about an hour and a half each week, relying mainly upon instructional materials she accumulated at teacher workshops, garage sales, and from around her home. A science textbook was not available for, or for that matter desired by, Ms. Vasenda.

Ms. Vasenda was provided with a full-day training on the curriculum and the MBL system prior to using the materials in her classroom. The curriculum was developed around a three-phase Learning Cycle approach because of its utility in helping children generate solid understandings of key

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* Pseudonyms have been used to replace all subject's actual names.

science concepts (Francis, 1987: Renner, 1988). The first three weeks of the curriculum centered upon the concept of blocking light. Activities involved the students in measuring the amount of light that was transmitted through different sets of materials, including colored plastic filters, white sheets of paper, and sunglasses. The second three weeks addressed the concept of bouncing light. Activities in this section of the curriculum included using the light probe to detect when a reflected beam of light was being directed in a certain direction. Another activity had the students inferring the orientation of a mirror inside of a closed box by measuring the amount of light emitting from several openings cut into the sides of the box as a flashlight beam was directed into one opening. The final two weeks of the unit served as a synthesis of the concepts of blocking and bouncing light. Each group of students was engaged in a unique activity with the results and findings ultimately presented to the rest of the class.

Data sources for this study were videotapes of classroom sessions, individual interviews with the teacher, samples of children's written work, and field notes taken by the classroom observer. The software that was used is commercially available and was originally written for use in secondary and college-level science classrooms. The software was slightly modified for this study so that column graphs of light intensity would change in height at the instant that the light level changed. This instantaneous representation of data on a computer screen is commonly referred to as real-time data. With this software, the students could measure light intensities as discrete samples, and each sampling would be represented with a distinct column called a LightBar. The first section of the curriculum made exclusive use of the LightBar graphs, but as the unit progressed, the line graph was also introduced to and used by the students.

FINDINGS

As a consequence of extensive reviews of the data, three assertions have been derived. Each of these assertions will be addressed individually, but there is certainly commonality across these areas.

Assertion 1: The students developed an increasingly sophisticated understanding of graphs and how they related to light during the course of this study.

Wells (1986) detailed how young children learn to use language by actively practicing its use. Conversations with parents serves not only as a testing ground for the development of vocabulary and grammatical conventions, but the talk also assists the construction of deeper understandings of the topic under discussion. The development of spoken English language described by Wells parallels the development of the students' "graphical literacy" as they worked with and talked about the light probe.

One day, during the "blocking light" segment of the curriculum, the teacher conducted a whole class discussion about some activities that the students had worked through the week before. During one activity the students used the light probe to measure how much light passed through various pairs of sunglasses. Measurements were taken by sandwiching a sunglass lens between a flashlight and the light probe; data were represented as LightBars. The height of each LightBar corresponded to the intensity of the light that entered the light probe after having passed through the lens of the sunglasses. The amount of light that a given pair of sunglasses blocked was inversely related to the height of the LightBar.

The students had brought in several pairs of sunglasses from home to supplement those provided by the teacher. Each pair of sunglasses was marked with a lettered tag. Below is part of the discussion about this activity:

VIGNETTE 1. Classroom conversation about sunglasses and LightBars (segment **19.00.31**)

Mrs. Vasenda: More than telling me which ones you found to be the worst and the best or whatever, I want to know...the thing that I want to ask you is, "How did...How DID you know that one pair of sunglasses was better than the other." What did you use as an indicator? Ellen?

Ellen: The LightBars [she is using her index finger to indicate the height of a LightBar]. If it's...if it's...When you try a pair of sunglasses, if it's high it means lots of light is coming through...

Mrs. Vasenda: ...okay...

Ellen: ...and if it's low, it means not lots of light are coming through.

Ms. Vasenda: Okay. So a high LightBar -- a lot of light's getting through. A low LightBar, not much light is getting through. Peg, did you want to add something to that.

Peg: When I was doing it, I put the darkest ones, like that [pair labelled] A, and I stuck it to the light probe...

Ms. Vasenda: ...um hmm...

Peg: ...and hardly any light was coming through,...

Ms. Vasenda: ...um hmm...

Peg: ...only like that much [she is holding her thumb and index finger about a centimeter apart] light came through.

As part of the process of communicating what they found, the students were attempting to work the data into their talking. At this point in the development of their graphical literacy, the students made use of hand gestures to relate the types of data they collected; when the thumb and finger are far apart, that means that the LightBar was tall. Articulating how this data relates to the intensity of light entering the probe was problematic for the students. One explanation for this struggle is the sequence of concepts that must be linked, or arranged in a string (White & Gunstone, 1992), in order to reach and communicate a full understanding. This string can be represented as: light passes through the lens --> some light is blocked --> the remaining light enters the probe --> the LightBar rises to a height representative of the light's intensity. Initially, children tend to circumvent the intermediate events and will state that when a light source is brighter, the LightBar gets taller.

While this is an accurate indication of a cause and effect relationship, it does not completely explain the interaction between the lens and the light.

A second bit of insight into the students' adeptness with graphs comes from an assessment task that was used as a follow-up to the Mystery Mirror activity. In the activity about which the assessment addressed, one student in each cooperative group was designated as the detective who had to determine the position of a mirror inside of a box by using the light probe to measure the amount of reflected light coming out of openings cut into the sides of the box. A flashlight beam was directed into one of the openings leaving five other slots where the light probe could be inserted. The assessment task required the students to first match the correct graph of five LightBars to a sketch of a mirror positioned inside of the box. The second portion of the assessment task asked the child to draw a mirror so that its position in the box would produce the graph of five LightBars that was provided (see Appendix 1).

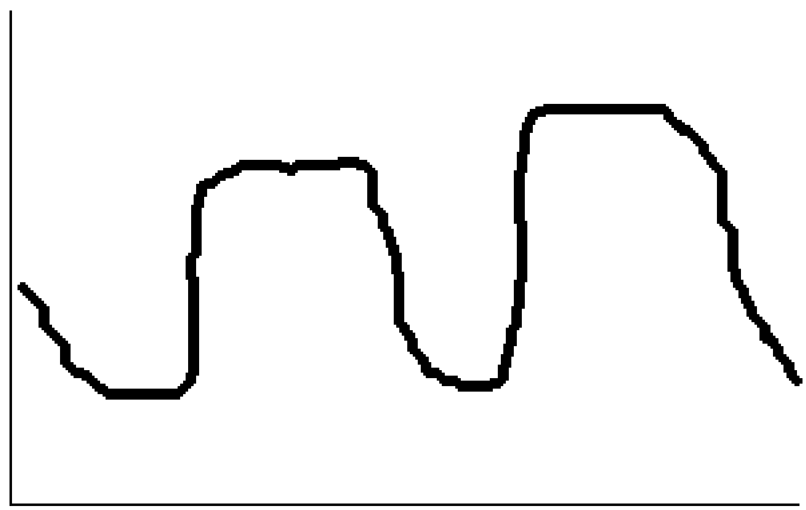
Most of the students correctly selected graph B in the first part of this activity. When prompted to draw on the picture what they thought happened to the light coming out of the flashlight, those students who did not select graph B drew diagrams that indicated that they had yet to understand how light travels after it reflects off of a mirror. In the second part of this assessment task, student drawings fell into three categories. The first category included those that did not show a mirror oriented so that the light was reflected to opening #4. Such drawings were characterized by curving lines showing light moving in all kinds of ways.

The second category of drawings showed a mirror roughly positioned so a beam or line of light travelled from the flashlight to the mirror and out of hole #4. This was our anticipated "correct" response. However, several of the students also tried to account for the medium heights of LightBars #1 and #5. The reason that these two LightBars were shown at intermediate heights on the handout was because that is what the graph would actually show because of the diffusion of some light to these holes. Recognizing that showing all LightBars but #4 at low heights would have simplified the task for the children, it was suspected that many would have noticed that such a graph was inaccurate. Drawings in this category, showed a beam or line of light reflecting off of the mirror at the same angle as it approached the mirror (as described by the Law of Reflection which, incidentally, was never formally taught to these students). These pictures, however, were supplemented by additional lines or beams of light that, while not reflecting at the proper angles, nevertheless were directed at openings #1 and #5. For these students, it appeared that their understanding of what the LightBars represent was in conflict with what they understood about the properties of reflecting light.

The bar graphs were the representations of light data that were most extensively used by the students. As they progressed through the curriculum, they were directed to make increasing use of line graphs. One Friday afternoon, the researcher told the students that he would set-up the MBL so that it would collect data about the light coming in through the classroom window for the entire weekend. The class was asked to describe what they thought the line graph on the screen would look like when they came in on Monday morning.

Several different predictions were put forth and the classroom teacher asked a few of the students to draw their predictions on the chalkboard. Michelle drew her graph something like as appears in Figure 1. The teacher asked Michelle to explain her drawing. She said that Saturday was represented by the first hill and Sunday as the second hill. The teacher said that she noticed that the Saturday hill was not as tall as the Sunday Hill. Michelle said, "I heard the weather report and it's going to be partly cloudy on Saturday and sunny on Sunday." This third grader apparently had a clear and working understanding of both dimensions of the graph: the dimension of light intensity on the vertical axis and the dimension of time along the horizontal axis.

Figure 1. Line graph showing Michelle's prediction of light data over a weekend .

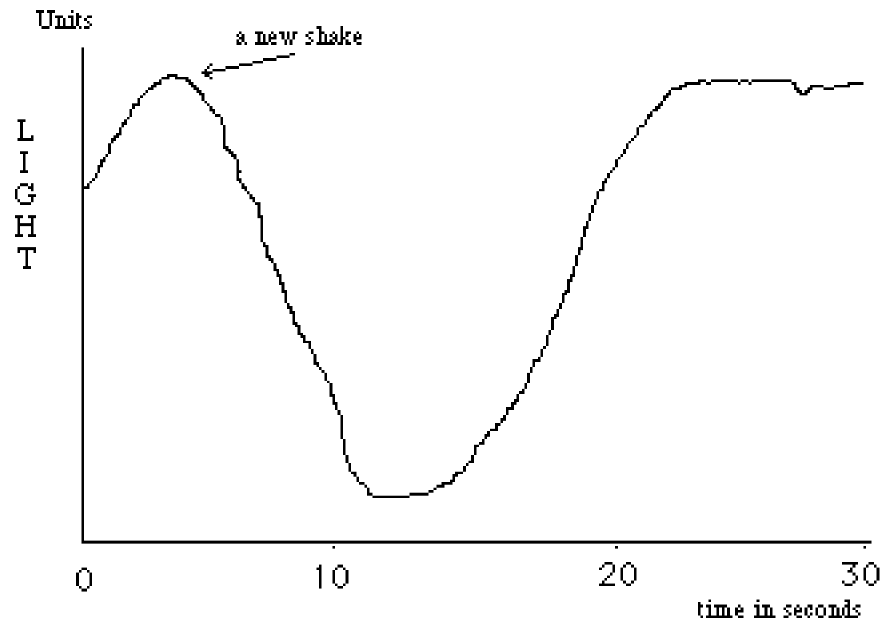


Assertion 2: In the hands of these third graders, the light probe and its interface with the computer served as tools for investigating light and informing their understandings of its behavior.

One activity near the conclusion of the curriculum unit was called Snow in a Jar. The idea for this activity was prompted by the memory of snow globes, water filled containers with small white particles that swirled about a miniature winter scene giving the impression of a blizzard in progress. For this activity, the students were given a sixteen ounce, plastic beverage bottle. They put two spoonfuls of multicolored glitter into the bottle and filled it with water. With the lid securely in place, a few vigorous shakes would cause the glitter particles to swirl about. Most of the glitter settled to the bottom of the bottle after it sat undisturbed for fifteen seconds. For this activity, the students were instructed to shake the jar of glitter, place it between the light probe and a flashlight, and collect data with a line graph.

A group of five students presented their findings to the rest of the class. Each group was doing a separate activity and this sharing to the rest of the class was intended to clue other group's into what they should and should not do when it was their turn to perform this particular activity. Andy was this group's self appointed leader and spokesperson. During their presentation, Andy frequently referred to his printout of the line graph, a facsimile of which appears as Figure 2.

Figure 2. Line graph from Andy's "Snow in the Jar" activity.



The explanation given for this graph was that when the glitter was swirling, not as much light could get through to the probe. As he explained this phenomena, Andy used his fingers to show light passing into the bottle. The reason for the two peaks on the graph was because the computer began measuring light a few seconds after the command to do so was given. Realizing from the real-time display of light intensity that the probe had "missed" the beginning, Andy's group shook the bottle a second time. By the end of the graphing interval, most of the glitter had again settled to the bottom.

Through the presentation to the rest of the class, it was clear that Andy and several other students could successfully relate the phenomena of blocking light to the data collected and represented by the computer. The action of the glitter sparkling as it floats through the water is very attractive; several students stated that they thought they looked like stars. But the presence of the probe took this simple toy to a higher level. No longer was this jar of metal flakes only pretty, it also became a catalyst for investigating the change in light transmission through liquid over time.

Assertion 3: The use of the light probe prompted the students to formulate questions that they could subsequently test and investigate.

One of the goals of the curriculum was to help the students recognize the utility of the light probe but to do so without having them discount the importance of their eyes. Because the light probe that was used was photometric (it "saw" the same range as does the human eye) its ability to differentiate colors was not as reliable as normal human vision. In the Colored Filters activity, students were to use the probe to measure how much light was blocked by different colored plastic filters. Prior to this activity, Ms. Vasenda had the students discuss some of their ideas related to the probe and the filters.

VIGNETTE 2. Classroom conversation about Colored Filters predictions (segment **19.18.35**)

Ms. Vasenda: Today, if you are working on the computer, and Monday if you're not doing it today, you're going to be working with color, and your going to...Let me just show you the materials you will be using. [she pulls four small rectangles of red, green, yellow, and blue plastic from an envelope] These are the color filters that you will be using with the computer. And I'm wondering if you can make any predictions cause you were very good at predicting which pair of sunglasses would block the light the best and that kind of thing. Do you have any predictions about how the computer will handle color? What do you think is going to happen to your LightBars now? What do you think Ellen?

Ellen: Like if you used yellow, I think the LightBar will go high. And if you used blue, I think the LightBar will go low.

Ms. Vasenda: Tell me why you think that. I think that's a good way of thinking.

Ellen: Because they're darker.

Ms. Vasenda: Okay. And it will do what more?

Ellen: Block light more. That [pointing to blue] will block light more. And that [pointing to yellow] will let the light come in more.

Ms. Vasenda: Okay. Theresa, what do you think?

Theresa: I think if you tried all of them together it wouldn't work as well as like...it would block more umm light...the LightBar and so, umm, you couldn't see really anything. But if used about one, the yellow one, you could see more...

Ms. Vasenda: So you're suggesting to use...Ellen was talking about using them separately, blue and yellow. And you are suggesting that maybe you could use multiples, you could combine them. Miguel.

Miguel: You know that one you were holding, the blue and the yellow?

Ms. Vasenda: This? Uh huh, uh huh.

Miguel: I think that if you put them both together, I think that the LightBar will still go high.

Ms. Vasenda: Do you think so? Tell me why.

Miguel: Because they look like the light. Because they're not so dark from the red and green.

Ms. Vasenda: Okay.

Miguel: I think the light can go a little...I think the light can go past it, umm...

Ms. Vasenda: ...that it can go through...

Miguel: ...with lots of light.

Ms. Vasenda: Okay. I think that's going to be fun to see. So you're going to combine a yellow <u>and</u> a blue. Because, Ellen you're saying yellow will let it through, blue will block it. And he's saying combine 'em and see what happens. Michelle?

Michelle: If you combine them, I wonder what will happen because like if you combined three colors, and two of them were dark, and one was light I wonder what would happen.

Ms. Vasenda: I know. That would be kind of fun to see, how they...how they mix together.

A striking feature of this discussion was the genuine sense of intrigue that this investigation posed for the class. The students felt confident in predicting which filter would block the most or the least amount of light. Yet the impact on the light's movement through multiple filters was apparently open to speculation. What we find encouraging from this activity is that the "I wonder ifs...?" can actually become fulfilled. Students had enough facility with the computer and probe to determine what indeed will happen to the amount of light that is blocked when yellow and blue filters are stacked together. Realizing that eight weeks out of a school year is a luxurious amount of time by typical curriculum development standards, we left with the sense that the students would have continued to pose questions and use the computer to help solve it. Taking a discussion away from just the philosophical and letting it evolve into a call for active investigation speaks well of the MBLs significance in informing children's understandings of the scientific inquiry process.

DISCUSSION

While the intent of this study was not to posit the developmental nature of children's conceptions of light, such an effort has been undertaken elsewhere. With Piagetian stage theory as his framework, Monk (1991) reanalyzed published investigations of children's conceptions of light and assigned explanations to various levels of development. While at first glance this scheme nicely organizes the range of alternative conceptions typically expressed by children, the shortcomings of the epistemological stages have called this system into question, largely because it does not adequately account for the complexity of children's representations of light and vision (Ramadas & Driver, 1991; Osborne, 1991). Trying to assign children's conceptions to a developmental map does not have the kind of predictive utility that such efforts seemed to hold in years past.

Our view of the need to reshape how science instruction is construed and conducted in elementary schools closely matches the suggestions of Shapiro (1988) who also investigated children's conceptions of light. She proposes that teachers and curriculum developers ought to draw out children's initial conceptions, clarify the nature of these ideas, and use this information to guide the direction of instruction. In addition, Shapiro urges those that write science curriculum and those who strive to implement it to empower children in controlling their learning, becoming more active in deciding what questions to pursue and what strategies to use in order to test theories. In terms of using MBLs, this implies that teachers will have to sacrifice their desire to predetermine exactly the activities in which the students engage when they work with the probes and computer. The teacher's role will shift from a provider of information to a provider of the support. While the teacher may help to clarify and refine the questions that the students elect to explore, s/he will have to trust the children's natural curiosity as the motivating force.

In his book “The Children’s Machine” Seymour Papert continues his advocacy for increased computer usage, especially in the elementary schools. His support for computers is strong but not single-minded because he acknowledges the computer as a learning tool and not as a cure for science teaching ills. His belief in the potential power of computers is the evidence that he has collect about how they open new possibilities to children:

> “I have no doubt at all that increased skill and confidence would come to many people if they engaged in more respectful and thoughtful talk about their learning processes. . . None of this absolutely requires computers. What we see...is how the computer simply, but very significantly, enlarges the range of opportunities to engage...in activities with scientific and mathematical content” (Papert, 1993, p. 145).

The impact of using MBLs upon teachers’ practice and students’ self-efficacy has been detailed by Kim (1989) and appears to reinforce the convictions expressed by Papert. Kim found that students engage in science activities in a more cooperative fashion when using MBLs that during non-MBL activities. In addition, the utilization of MBL in the study’s classroom reawakened the teacher’s awareness of the diversity among his students and led to modifications in his teaching practice. Perhaps other forces would have nudged the teacher to reconsider the individuality in his classroom, but the computer served as that nudge in this case.

Too often it seems that educators who support a constructivist view of science advocate the utilization of hands-on activities in ways which are decidedly counter to this epistemology. Most of my colleagues would reject the learning metaphor of the blank slate, yet there is some inconsistency between what they espouse and how they act. The core of my concern is that while we may no longer accept an instructional approach in which the teacher attempts to transmit knowledge to the student-receptacles, we may be transferring the task of providing “truth” to the materials that we want the students to use. So even though we might believe that knowledge cannot be passed directly from an adult to a classroom of children, our unequivocal support of concrete experiences belies our underlying presumption that scientific theories about light, evolution, and acceleration are inherently more accurate than the students' alternative conceptions.

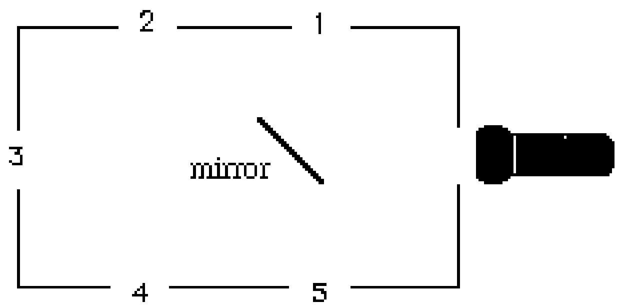
Newman, Griffin and Cole (1989) described their efforts at applying Vygotsky's "zone of proximal development" idea to teaching in elementary classrooms. In their discussion of the implications of this theory to the design of instruction, they caution against viewing computers as a means in and of themselves to improve children's learning. Effective instruction, whether with or without computer technology such as MBLs, must place sufficient emphasis upon opportunities for quality interactions amongst all of the participants in the learning process:

> "Our own approach in the area [of computer mediated instruction] is to emphasize the social environment of instructional materials. This contrasts with the tendency in cognitive science approaches to look at the student-machine interaction rather than seeing the machine as a mediator between the teacher and the student or the teacher as a mediator between the student and the machine. Designing more effective instruction must involve designing systems of social interaction and social organization. Better textbooks or better microcomputer "courseware" will be only as good as the multiple settings in which teachers get them to function" (Newman, Griffin & Cole, 1989, p. 148).

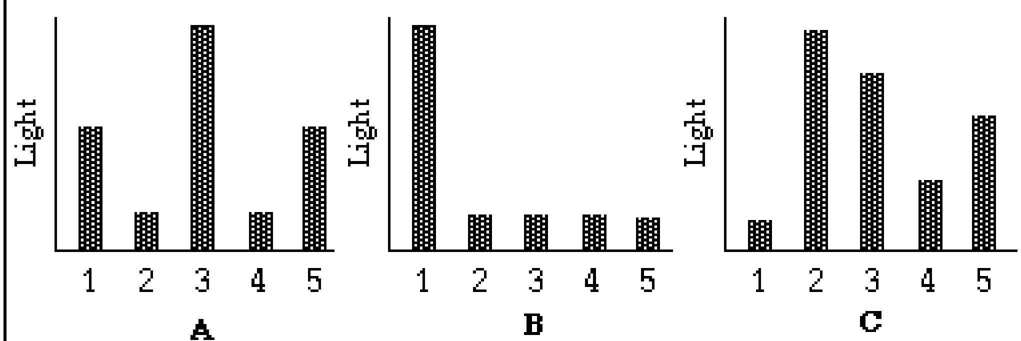
The extraordinary amount of energy required to shift teachers' conceptˇons of science teaching to one that builds upon a constructivist epistemology has been convincingly described by Neale, Smith & Johnson (1990). Their efforts to shape primary school teachers' science teaching practice toward a conceptual change approach were generally successful, but required substantial support and coaching as well as a considerable investment of time on the part of the research team and the teachers. They suggest that courses for teachers need to address not only science content matter but also the pedagogical-content knowledge issues required before teachers can be expected to support children in constructing their own understandings.

From our work with elementary school children and teachers as they interact with the MBLs, we have grown to recognize the potential for this technology to support and advance individual's understandings of important science concepts such as reflecting and the filtering of light. Furthermore, the MBL gives children access to data in the form of graphs which they become increasingly more capable of interpreting. Aside from the conceptual development that we have witnessed, skill at interpreting, analyzing and synthesizing data is furthered through the use of MBLs. The MBLs serve as tools within the classroom environment, but they neither create nor sustain a climate that permits students to propose, test, and revise their theories of the behavior of light. This is the role of the teacher whose job has not been replaced by the computers' presence, but rather is being reconsidered, reconceptualized, revised, and perhaps revolutionized.

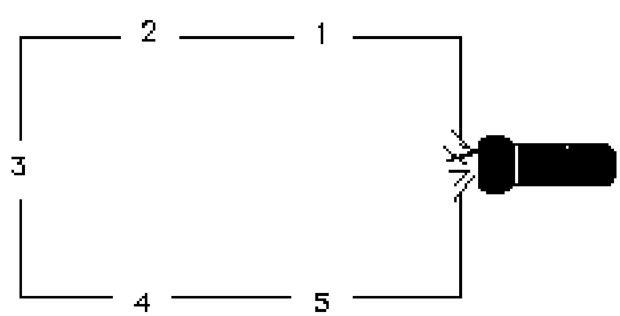
APPENDIX 1. Mystery Mirror Assessment Task

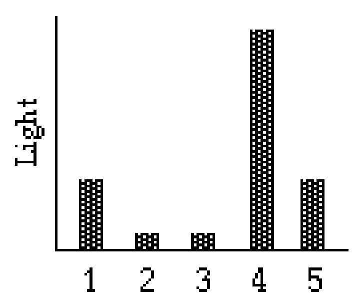


Which graph would the MBL and the light probe make? ____



Draw where the mirror would be that would make this graph.





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