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Multimedia editing to promote science learning

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Abstract

This paper examines the cognitive and affective impact of a multimedia editing task. Students were highly motivated to work cooperatively and without teacher supervision to search out and remember science content materials from a wide variety of resources, with visual recall being especially promoted. During this process, the students repeatedly demonstrated empathy for their audience's needs and interests. They viewed the creation of externally valuable (i.e. useful outside school) materials as the most important aspect of the experience. Although technology had an important role in student activity, it appears that it was the task that was vital, not how it was accomplished.

Multimedia editing to promote science learning

Introduction

In a 1985 article Raymond Pea comments that cognitive technologies act to redefine our culture by shaping who we are because they change what we do. This study examined students and teachers working in a radically redefined educational culture. The setting was a school located within the boundaries of a large zoo. This extraordinary situation provided opportunities for students to learn science from direct observation of animals and plants, through interactions with zoo curators, and from the extensive holdings of the school's media center. This was supplemented by the incorporation of computers, electronic cameras, color page scanners, videodisc and CD-ROM drives, sound digitizers, and commercially available instructional and productivity software. The purpose of the study was to determine how nine students used this resource-rich environment to teach science topics to themselves and to others. The task placed before them was to produce an extensive series of information screens for visitors to the zoo. A touch screen kiosk would display their creations. It was up to the students to create interesting and informative combinations of audio, still video, short narrated movies, and colorful graphics. This research follows Pea's recommendation of the simultaneous creation and study of new tools that might change the processes of human learning. More specifically, we wanted to examine how students and teachers interact with the science content, the technology, each other, and other groups (zoo curators and visitors).

Studies of cooperative learning (cf. Johnson, et al., 1981) strongly suggest that cognitive development is facilitated by peer interaction. The situations set up for students working on this project put a premium on the sharing of efforts and resources. Participants worked in groups of two or three when they were looking for information and creating multimedia screens. Vygotskian theory (Vygotsky, 1978; Wertsch, 1979) suggests that students' cognitive development might be enhanced by this type of social interaction. People who are more competent assist those less expert by first helping or scaffolding their thinking and then fading assistance as the learner builds understanding and gains mastery of the material. The learner is an active participant in this process, which often takes place during problem-solving situations. The learner's understanding is mediated by his or her practical activity and existent knowledge. The data collected during this project describe situations where the computer coordinator, zoo staff, and especially the students acted as the more competent "teacher." Those observations also indicate that it is important to consider the zoo visitors who used the kiosk materials created by the students. Although these people did not directly influence cognition in the Vygotskian sense, they were definitely seen to have had an effect.

Research indicates that the editing assignment and the multimedia/hypermedia nature of that task should promote the learning of content. Champagne & Klopfer (1977) note that reflective thinking has been considered important for learning since John Dewey first suggested it in the very first issue of the *Science Education* journal in 1916. By requiring the student editors to select from a wide range of materials only those bits of multimedia information that they judge appropriate for their audience, learners were encouraged to thoroughly evaluate the importance and relevancy of the content material, as Perkins (1985) suggests when he states that teachers and students should “design knowledge.” Quellmalz (1985) defines higher order thinking as occurring when students identify the job to be accomplished, define its essential elements, judge and connect relevant information, and evaluate the adequacy of that information. To a close approximation, this is a step-by-step description of the editing process studied here. Sternberg (1984) delineates three components of knowledge acquisition which have direct analogs in the editing task: (1) selective encoding–picking out relevant information for further processing, (2) selective combination–putting information together in a way which has meaning for the learner, and (3) selective comparison–noting relationships between new information and old information

Shuell (1986, p. 415) notes that “learning is an active, constructive, and goal-oriented process that is dependent on the mental activities of the learner.” This traditional understanding of constructivism has been an important tenet of educational psychology for some time. Even before Vygotsky’s work, Piaget (1954) described his view of knowledge construction as a developmental process. This basic idea of learners constructing their own knowledge has recently been extended in a variety of ways. Scott, Cole, and Engel (1992) describe a cultural constructivist approach which stresses that the instructional interactions are mediated by cultural artifacts–in our case, a unique physical setting in conjunction with access to advanced educational technology. Recent advances (Anderson, 1992) in the neurosciences have begun to elucidate how some fundamental mechanisms of nervous system activity are consistent with a cognitive view of constructivist models of learning. Seymour Papert (1990) takes the tenets of constructivism one step farther and modifies the name of the theory itself to help explain what he means.

> We understand "constructionism" as including, but going beyond what Piaget would call "constructivism." The word with the *v* expresses the theory that knowledge is built by the learner, not supplied by the teacher. The word with the *n* expresses the further idea that this happens especially felicitously when the learner is engaged in the construction of something external or at least shareable...a sand castle, a machine, a computer program, a book. This leads us to a model using a cycle of internalization of what is outside, then externalization of what is inside and so on.
>
> I like to formulate a major theoretical issue as "constructionism vs. instructionism." This does not suggest that instruction is bad or useless. Instruction is not bad but overrated as the locus for significant change in education. *Better learning will not come from finding better ways for the teacher to instruct but from giving the learner better opportunities to construct.* (emphasis in the original, pg. 3)

The key to what Papert is saying is the empowerment of students–giving them facilities to create something. Their work has meaning and importance to themselves and others. DeCorté (1991) noted that these "authentic activities" should be representative of future tasks and problems, provide many opportunities for social activities, and be rich in resources and learning materials. The editing assignments were designed to meet all these requirements.

Research suggests that the multimedia aspects of the student task should also add to the educational efficacy. Kolers & Brison (1984) comment that design features such as color and contrast not only serve to bring content topics to mind, but are themselves retained for the long term like the semantic or linguistic features of words describing the content. In general, visual stimuli has been found to be superior to verbal stimuli in children's retention and recall: learners recall more information when responding in pictorial form than in verbal (Howe & Vasu, 1990). The same study noted that two different modes of sensory input lead to greater retention and recall than either mode by itself. This is certainly an indicator that multimedia can be an effective instructional tool.

The linkages that students were required to build between concepts should also promote learning. Considerable work on concept mapping (Novak, 1990) implies that having students connect key ideas together in a hypermedium should create a framework for additional learning. Lehrer (1991) cites hypermedia as supporting learning by requiring students to organize information into multiple representations, by promoting a sense of authorship (if they are creating a non-trivial product), and by requiring them to consider their audience.

To summarize, the theoretical underpinnings of the student assignment indicate that the editing task and its multi- and hypermedia aspects provide a rationale to expect a positive impact on student learning.

Description of the study

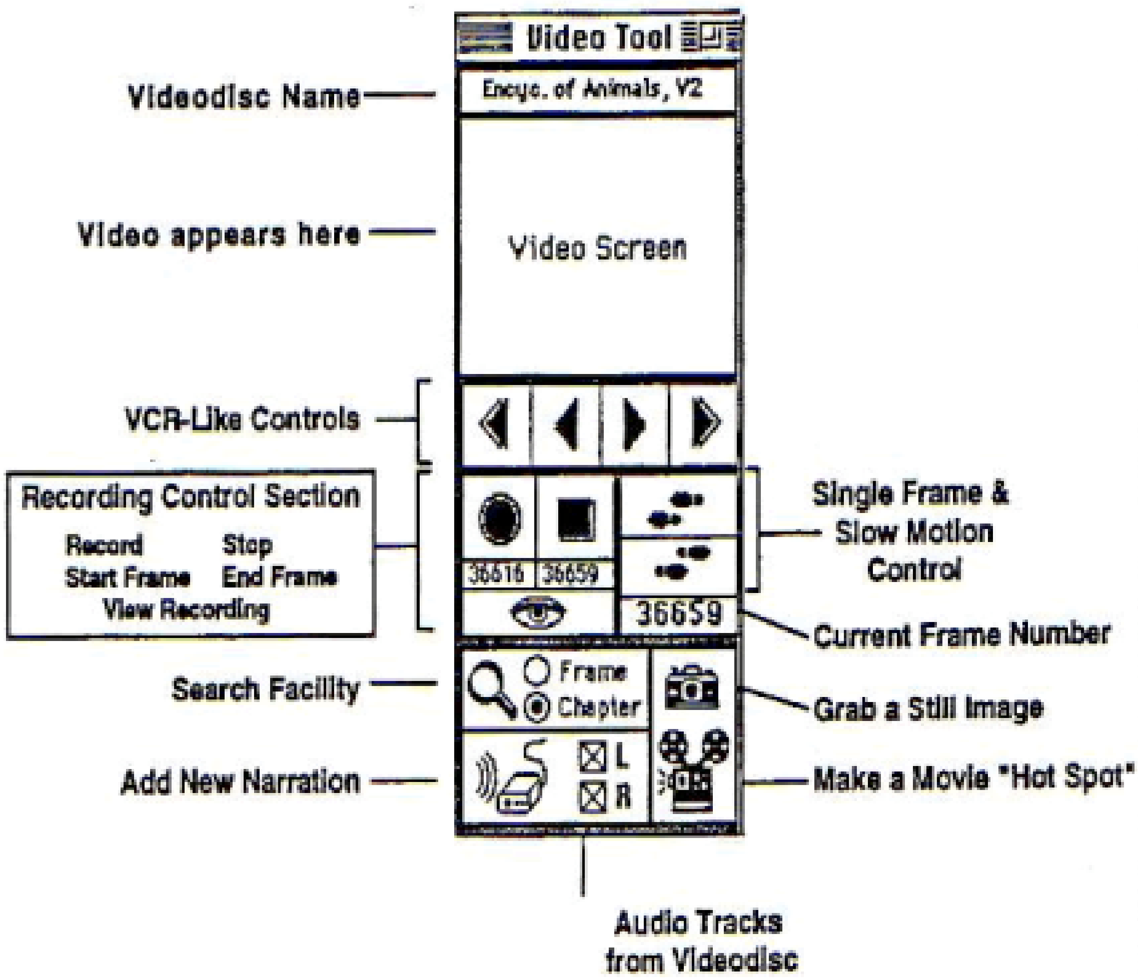
The setting

The school in which this research took place is an urban science magnet school established in the early 1980's. Approximately 65% of the 200+ students belong to recognized minority groups. Typical class sizes are 21 for seventh- and 29 for eighth-grade. The school has won several awards for its programs and often acts as a model of how computer technology can be incorporated into various aspects of middle school education. As noted earlier, it is located on the grounds of a large, metropolitan zoo. School and zoo staff work to help everyone take advantage of this proximity. The students come from the local neighborhood or are bused in from the surrounding region. A lottery must be held to select students for the limited number of spots available. In other words, the school appears to be a modern, highly desirable place for students to focus on science. Computer technology is readily available, with at least one networked microcomputer in each classroom. An expertly staffed computer lab with a wide assortment of software and hardware is also on site. Students can use the lab for individual work or recreation when it is not being used by a class. Because of the technology-rich environment, all students had already attained a very high degree of computer literacy. This should have reduced the Hawthorn effect, which is often present in studies of technology in a school setting.

The subjects were a racially mixed group of nine seventh- and eighth-graders who each worked several hours per week on the project over the course of an entire school year, plus a few students who piloted the materials during the first year of software development. Participating students were selected by the head computer coordinator on the basis of their reliability and availability. No particular efforts were made to include or exclude students with academic abilities or deficiencies. There were two computer coordinators, three teachers, and half a dozen zoo and museum staff involved with the project at various times. A teacher training session held during the summer following pilot testing was attended by six teachers/support staff and was taught by both coordinators.

The Software

Ambron (1990) describes composing with multimedia as "adding degrees of freedom to a painter's palette..." This idea was kept forefront during the design of the multimedia editing environment. The software is a hybrid of HyperCard and SuperCard. It also utilizes an interface board to permit video display directly on the computer screen. Students did all their work from an editor program which created information screens for the touch-sensitive kiosk. The editor provides a variety of tools for student use. By selecting items from a menu, students could work with an on-screen audio recorder which looked like a cassette tape recorder, a video tool which functioned the same way their home VCR's did, color painting and text tools, and a data linking tool for connecting pieces of information together. Students normally used these tools to make "hot spots" on the kiosk screen. By touching these areas, zoo visitors could see and hear animals, look for more information, or even print out a handout sheet, complete with a map of the zoo and student-generated questions and comments about the animal on the screen.



The video tool (Figure 1) provides an example of how easy it was to create multimedia. Students used the VCR-like controls to operate the videodisc player until they saw the desired video segment appearing in the small

“Video Screen” area. Clicking on the camera icon placed a “snapshot” from the videodisc onto the screen being created. Alternately, by use of the record button, a video sequence (with student-controlled audio) could be linked to a touch control automatically generated and added to the information screen. Later, when a visitor touched this spot, the movie would zoom out to fill the screen and play the video and audio as edited by the students. Similar tools allowed creation of strictly audio information, text, colorful drawings, and images captured from a scanner or electronic camera. Anything placed on the information screen could be moved, resized, and deleted through the use of a single set of keystrokes.

Methodology

Many authors (cf. Magoon, 1977; Rist, 1982; Smith, 1982; Evertson & Green, 1986; Levine, 1990; and Strauss & Corbin,1990) have described qualitative research techniques and their applicability. Detailed textual analyses of videotape transcripts made this research partly microethnographic, described by Levine (1990) as focusing on “interactional work that assembles systematic patterns of social behavior.” The student editing sessions provided particular insight into the different types of student/teacher roles, the immediate and long-term goals of individuals and groups, and the participants’ emotional responses to the situation. Situations where students talked to zoo visitors and staff revealed the clearest view of what students saw as their role in the project.

Insert Table 1 near here

The analysis began with the open coding methodology discussed by Strauss & Corbin (1990). Labels were attached to the activities portrayed on each line of the transcripts and field notes. These original labels were mostly descriptive in nature, including breakdowns as to whether a student was talking to another student or to a teacher, if students were referring to their audience, relaying a piece of information they had gathered from a resource, etc. As more of the data was reviewed and a better impression of the central concepts emerged, the labels were revised. For example, continued analysis led to a reclassifying of some of the teacher/student dialog into a new "teacher-directed action" category. This continuous category refinement eventually became what Strauss and Corbin call axial and selective coding. This can be described as making connections between categories and deciding on a "core" category which contains the overall pattern distilled from the data.

Besides reviewing transcripts of student interactions, observations of teacher training sessions were utilized to provide clues as to what the computer coordinators felt were the important educational aspects of the project. Formal and informal interviews with participants allowed an alternative method of approaching the categories extracted from the videotapes. Invariably, these interview transcripts would correlate closely with the observation transcripts. Student-generated information screens, handouts, and the reference materials used by the students were also collected and studied. Researchers' notes were regularly compared with the computer coordinator's impressions in an effort to address validity concerns and identify observational biases.

During this nearly two-year long project the students, teachers, and staff became very familiar with the research team. According to Seidman (1991) such familiarity could lessen the tendency toward guarded answers. We had additional reasons for confidence in our data gathering protocol. Jackson, Berger and Edwards (1989) cited Schoenfeld's observation that the natural tendency of people working together to express their thoughts can result in less contaminated data than that generated by think-aloud methods. Sharing responsibility may also decrease the pressure to produce a behavior which may be seen as desired by the investigator, a weakness of the think-aloud protocol when the goal is to shed light on decision making processes. It was particularly encouraging in this study to discover that the students often appeared to forget about the presence of the video camera. The camera, set off to the side on a tripod and then left running, occasionally caught them talking about non-school topics or using language which they probably would not have been using if they had remembered that their words were being recorded.

Cognitive and Affective Impact

The final categories which evolved during the data analysis are detailed below. Writing for an audience emerged as the "core" category in the analysis of the videotape transcripts. Papert's (1990) extension of constructivism to constructionism seems particularly appropriate here. Student awareness of their audience and the importance of their task dominated the recorded data.

Writing for an audience

The value of purposeful student writing assignments has long been recognized (Florio, 1979). Writing for others results in better writing (Reinking, 1986; Cohen & Riel, 1989). Project teachers recognized this as well. During the teacher training session, one person commented: "What's really exciting about this project is that the kids realize they have an audience, an extensive audience. Any visitor, by touching the screen, can see his work."

In this study we saw many instances of student concern for the people who would be viewing their multimedia information screens. This was perhaps most evident during the discussions students had while designing and creating new materials. "They [visitors] don't want to read a whole lot...just the main points." This self-imposed requirement of extracting the most important information and organizing these facts into interesting packages required cognitive processing at Bloom's (1956) classic analysis, synthesis, and evaluation levels.

This same consideration for audience was also present when non-textual information was being assembled by the students. "You want a picture here. Just a little one. Just so they know what it is." Or similarly: "You need more close-up... Is there a part where there's more of the animal? You can't tell what it is." Here one student is asking another for additional information–not only showing their concern for the clarity of their presentation, but also indicating that during the editing process students actively encouraged each other to recall information.

Empathy for the people viewing their work also led students to consider the issue of navigation through the information. This often led to revisions of screen content or changes in the links between screens. This is evident in the following excerpt from the transcripts:

> Student: "This whole kiosk thing...when it is done and down there...there is going to be so many different things that they are going to get lost in it."
>
> Teacher: "That is the idea."
>
> Student: "Because I mean, you get into one thing and there is no going back to the first thing...once you get off in a different direction ..."

This led the student to make several modifications in her screens to make sure visitors could "back up" to earlier hypermedia nodes. She shared this idea with the others so that similar backlinks were placed in all screens created from that point on.

Concern with accuracy of information

Students were nearly as concerned with being accurate as they were with making the information interesting. At one point they were greatly distressed by the fact that an animal video did not exactly match what they recalled seeing in the zoo exhibit. This is apparent in these field notes:

> The group [at the editing screen] seems agitated while reviewing their sheep video clip. They do not even notice Mrs. B [the science teacher] who came into the room and now comes up to the group from behind... She interrupts and tells them that their Current Events screen is a “really big service to the zoo.” The students appear to ignore the compliment. A. asks Mrs. B, “Do you know if our Rocky Mountain Bighorn Sheep in the zoo have white butts? I don’t think they do. We have some pictures from the videodisc, but they have white butts....We don’t want people to...[inaudible]”

Here the student not only demonstrates recall of a particular video sequence, but also specific facts about the zoo collection. They evidently discovered for themselves that “white butts” were a distinguishing characteristic of a particular kind of sheep. The editing situation provided an intrinsic motivation for them to search out this additional information.

Direction of students

A very definite reversal of student and adult roles was seen over the course of the study. During the first month, the computer coordinator and zoo staff often dictated both the content and layout of the information screens. During the teacher training session this was encouraged by the coordinator:

"[Teachers, you should] think about the types of screens you would like the public to view." A careful design process was also suggested by the handing out of blank paper and telling the teachers and staff at the session to plan their screens on paper first. Later on, this technique was recommended to the students by the same coordinator.

When the students began using the editor, they were often told what information to include and how to incorporate it into a multimedia screen. This was usually accompanied by instruction in how to carry out a particular task with the software. For example, after demonstrating how to scan in some animal photographs, the teacher would explain the placement of the images onto a screen while telling students that these particular pictures would be good to use. The students occasionally appeared to appreciate the help, but within a few weeks they demonstrated a strong desire to work on their own. Once students had mastered the editor, roles rapidly changed. Students not only picked out what information and layout designs they would use, they also began showing other students and even their teachers how to best use the equipment and software. The computer coordinator mentioned that "Kids teaching other kids seems to work well." This growing confidence and expertise appears to be an outcome of the cooperative grouping established as part of the editing exercises.

Learning from the resources

Another change that occurred once the students became expert at using the technology was a shifting of their attention to the science content they were trying to convey. The editing groups would have to review a sizable body of information before they could decide what was important enough to display. They would usually review three or more videodiscs, zoo docent manuals, stacks of books and magazines from the library, and often interview zoo curators. The transcripts indicate that they retained a great deal of this information, especially the visual images.

> Student 1: "Oooh! Look at this one!" (a frame from the videodisc)
>
> Student 2: "That's enough! We already have three still frames to choose from!"
>
> Student 1: "Well, I found another good one!"

Duell (1986) noted that although identifying the main ideas about a topic and writing summaries of information are important study skills related to metacognition, these abilities are usually developed gradually. The editing tasks stimulated these metacognitive competencies fairly quickly. Students had few difficulties deciding on the most important concepts as they read materials and viewed video clips. There also appeared to be transfer of some skills to other non-science classes. A non-participating teacher reported that two students were talking about making a poster and what to include on it, saying that they "got the idea from the kiosk." While it is not clear if the students were discussing layout or content, it is obvious that they were applying what they had learned while editing to other settings.

Affective Impact

It quickly became obvious that both students and teachers were very enthusiastic about the project. The fact that the school was already inundated with technology implies that it may have been the editing tasks that were so exciting. Teachers viewing the students using the system repeatedly commented, “This is great!” The students began skipping study halls and lunch periods in order to work on their screens. Often the computer coordinator would arrive in the morning to find students who had come in early and were waiting for her to open the door. One of the students remarked, “Did you see my program? I’m getting the hang of it!”

Many other technology-oriented projects have seen similar enhancement of motivation. For example, Scardamalia and Bereiter (1990) commented on student excitement with their CSILE project. Harel and Papert (1990) report corresponding findings in their studies. One of the few times that morale was low during the entire two-year project was when students encountered programming errors in the editing environment. When that happened, they quickly became highly frustrated. They also were annoyed when visitors looking at their screens did not understand how to use the system. This was especially evident when very young children placed their palms on the screen instead of using a fingertip to touch a hotspot. This caused the kiosk to behave in unpredictable ways and resulted in rather harsh operating instructions from the observing students.

Student impressions of their role

The last student quotation noted above illustrates an unexpected finding–the students almost universally referred to what they were doing as programming. For example, during an open house, one of the students was explaining the project to a visitor: “We each find out things to put on the screens. I programmed this one. You can try it out if you want.” They also indicated on several occasions that what they were doing was similar to what newspaper and television reporters do in their jobs.

Curriculum integration

This is where the project was the least successful. The initial hope was to have teachers from many different areas working with students as they created new screens. As it turned out, the computer coordinator was the only teacher working on a day-to-day basis on the project, even though she made repeated efforts to involve others. Most other teachers, although expressing approval, declined to become involved. Often their only connection to the project was to release their students from class so that they could work on information screens, or to send current events for inclusion on the kiosk. On the other hand, many zoo and science museum staff members provided information and assistance to the students. It is not apparent from the data why the staff members were more willing to work with the students than the teachers were. Further work needs to be done to find ways to improve the incorporation of this type of task into instruction and across curricular areas.

Summary

The key finding from this study is not that technology improved learning or that the unique zoo setting made the project successful. What became clear while examining the data is that students saw that the work they were doing had importance outside the classroom. It was worthwhile for them to learn new material and uncover additional resources. In the case of this project, those resources were decidedly "high tech," but that was not a necessary condition. The data demonstrate the importance of designing curricula that incorporate realistic, highly involving tasks. By establishing an environment where creative thinking about the content material is combined with real-world assignments, students will learn content, enjoy the learning process, and recognize that they have created something worthwhile–i.e. worth their time and effort. Teachers in more typical schools, although probably not having access to as many technology-based materials as described here, almost certainly have suitable holdings in their schools and community libraries. These can be used by students to carry out interesting and *useful* projects.

References

Anderson, O. R. (1992). Some interrelationships between constructivist models of learning and current neurobiological theory, with implications for science education. *Journal of Research in Science Teaching*, *29*(10), 1037-1058.

Ambron, S. (1990). Multimedia composition: Is it similar to writing, painting, and composing music? Or is it something else altogether? In S. Ambron & K. Hooper (Ed.), *Learning with Interactive Multimedia* (pp. 70-84). Redmond, WA: Microsoft Press.

Bloom, B. (1956). *Taxonomy of Educational Objectives Handbook: Cognitive Domain*. New York: Longmans Green.

Champagne, A. B., & Klopfer, L. E. (1977). A Sixty-Year Perspective on Three Issues in Science Education: I. Whose Ideas are Dominant? II. Representation of Women. III. Reflective Thinking and Problem Solving. *Science Education*, *61*(4), 431-452.

Cohen, M., & Riel, M. (1989). Effect of distant audiences on students' writing. *American Educational Research Journal*, *26*, 143-159.

DeCorté, E. (1991, April). *Research on learning and instruction: European contributions*. Paper given at a seminar for the Graduate School of Education, State University of New York at Buffalo, Buffalo, NY.

Duell, O. (1986). Metacognitive skills. In G. Phye & T. Andre (Ed.), *Cognitive Classroom Learning: Understanding, Thinking, and Problem Solving* (pp. 205-242). Orlando, FL: Academic Press.

Evertson, C., & Green, J. (1986). Observation as inquiry and method. In M. Wittrock (Ed.), *Handbook of Research on Teaching* (pp. 162-213). New York: MacMillan.

Florio, S. (1979). The problem of dead letters: Social perspectives on the teaching of writing. *Elementary School Journal*, *80*, 1-7.

Harel, I. (1989). Software design for learning: On learning mathematics through instructional software design. In W. C. Ryan (Ed.), *Proceedings of the National Educational Computing Conference* (pp. 72-86). Eugene, OR: International Council on Computers for Education.

Harel, I. & Papert, S. (1990). Software design as a learning environment. In I. Harel (Ed.), *Constructionist Learning* (pp. 19-50). Cambridge, MA: MIT Media Laboratory.

Howe, A. C., & Vasu, E. S. (1990). *The Effect of Two Modes of Sensory Input on Children's Retention and Recall*. Atlanta, Georgia: National Association for Research in Science Teaching,

Jackson, D., Berger, C., & Edwards, B. (1989, April). *The Student as Grapher: Microcomputer-Assisted Thinking Skills.* Paper given at the meeting of the American Educational Research Association and the International Association for Computing in Education, San Francisco, California

Johnson, D. W., Maruyama, G., Johnson, R. T., Nelson, D., & Skon, L. (1981). Effects of cooperative, competitive, and individualistic goal structures on achievement: A meta-analysis. *Psychological Bulletin, 89,* 47-62.

Kolers, P. A., & Brison, S. J. (1984). Commentary: On Pictures, Words, and Their Mental Representation. *Journal of Verbal Learning and Verbal Behavior*, *23*, 105-113.

Lehrer, R. (1991). *Authors of Knowledge: Patterns of Hypermedia Design*. Paper presented at annual meeting of the American Educational Research Association, Chicago, Illinois.

Levine, H. (1990). Models of qualitative data use in the assessment of classroom-based microcomputer education programs. *Journal of Educational Computing Research*, *6*, 461-477.

Magoon, A. (1977). Constructivist approaches in educational research. *Review of Educational Research*, *47*, 651-693.

Novak, J. (1990). Concept Mapping: A useful tool for science education. *Journal of Research in Science Teaching*, *27*, 937-949.

Papert, S. (1990). Introduction. In I. Harel (Ed.), *Constructionist Learning* (pp. 1-8). Cambridge, MA: MIT Media Laboratory.

Pea, R. (1985). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist*, *20*, 167-182.

Perkins, D. N. (1986). *Knowledge as Design*. Hillsdale, NJ: Erlbaum.

Piaget, J. (1954). *The Construction of Reality in the Child*. New York: Basic Books.

Quellmalz, E. S. (1985). Needed: Better Methods for Testing Higher-Order Thinking Skills. *Educational Leadership*, 29-35.

Reinking, D. (1986). Six advantages of computer-mediated text for reading and writing instruction. *Reading Instruction Journal*, *29*, 8-16.

Rist, R. (1982). On the application of ethnographic inquiry to education: Procedures and possibilities. *Journal of Research in Science Teaching*, *19*, 439-450.

Scardamalia, M., & Bereiter, C. (1990, September). *A knowledge-building architecture for computer-supported learning*. Paper presented at NATO Advanced Research Workshop, "Computer-Based Learning Environments and Problem Solving", Leuven, Belgium.

Scott, T., Cole, M., & Engel, M. (1992). Computers in education: A cultural constructivist perspective. In G. Grant (Ed.), *Review of Research in Education* (pp. 191-251). Washington, DC: American Educational Research Association.

Seidman, I. E. (1991). *Interviewing as Qualitative Research*. New York: Teachers College Press.

Shuell, T. J. (1986). Cognitive Conceptions of Learning. *Review of Educational Research*, *56*(4), 411-436.

Smith, M. (1982). Benefits of naturalistic methods in research in science education. *Journal of Research in Science Teaching*, *19*, 627-638.

Strauss, A., & Corbin, J. (1990). *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: SAGE Publications.

Sternberg, R. (1984). *Mechanisms of cognitive development*. New York: W. H. Freeman.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wertsch, J. V. (1979). From social interaction to higher psychological processes: A clarification and application of Vygotsky's theory. *Human Development*, *22*, 1-22.

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1. Videotape of participants is made as non-obtrusively as possible.
2. Audio and activity recorded on tapes is transcribed.
3. Individual lines in the transcript are labeled for type of activity–open coding.
4. The labels are continuously revised until final categories of activity emerge–axial and selective coding.
5. Supplemental resources (student portfolios, content resources, etc.) reviewed for additional insights and to verify earlier conclusions.

Table 1: Outline of the data analysis process