The Mission to Mars Webliographer: A Principled Approach to the Design of a CSCL Tool

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Abstract

The Mission to Mars Webliographer is a tool which allows children and adults to collaborate and synthesize Internet resources for research in context rich, sustained learning environments. In communicating the process of software development and analysis that went into the Mission to Mars Webliographer, we use a framework first proposed by Koschmann et al. (1996). This framework is a four step model which articulates the desired instructional features of the tool, analyzes current practice in light of design goals, develops a specialization for the tool based on both the instructional requirements of the setting and the known capabilities of the technology, and produces an implementation that allows for adaptation to instructional practice.

Preliminary findings indicate that the Mission to Mars Webliographer is an effective tool for time management issues concerning student research in project-based classrooms utilizing the Internet. In addition, teacher interviews and classroom observations indicate that student's Internet use is more focused and on-task when utilizing the Mission to Mars Webliographer as opposed to more traditional Internet in research activities.

Keywords— Project-Based Instruction, Collaborative Learning, World-Wide Web, Learning Environments, URL Database Search Engine.

In this paper, we illustrate the reflexive nature between theory and practice (Glaser, 1994) in terms of the development of CSCL software for a problem to project-based environment (Barron et al., in press; Soloway, Krajcik, Blumenfeld, and Marx, 1996) known as Mission to Mars (Petrosino, 1994). Specifically, we will discuss the use of a computer tool called the Mission to Mars Webliographer which allows children and adults to collaborate and synthesize Internet resources for research in context rich, sustained learning environments. In communicating this process of software use and development, we have found the work of Koschmann et al. (1996) to be of particular assistance in providing a principled approach to the design of technologies for CSCL. After a brief explanation of the unit and past research, we will use the four steps of Koschmann et al.'s theory-based design of CSCL tools (see Table 1.0) to frame our discussion on the principles surrounding the Mission to Mars learning environment as well as the conditions which prompted the development and implementation of the Mission to Mars Webliographer. In this manner, we will demonstrate the reflexive nature of research and practice informing each other.

Table 1.0 Koschmann et al. (1996)'s Principled Approach to the Design of CSCL Tools

First Step: A Model of Effective Instruction and Design Goals	Articulate the desired instructional features of the planned innovation
Second Step: How May Technology Assist	Analyze current practice in the light of the design goals
Third Step: A Mutually Beneficial Marriage of Instruction and Technology	Develop a specialization based on both the instructional requirements of the setting and the known capabilities of the proposed technology
Fourth Step: Flexibility and Accommodation Through Creative Use	Produce an implementation that allows for adaptation to instructional practice

Background

The Mission to Mars learning environment is designed to assist students in the practice of reflecting on their own learning and to develop children's own monitoring skills with instructional support for sustained inquiry [1]. To facilitate this process, the Learning Technology Center at Vanderbilt University has developed a seven-minute video using existing NASA footage (Hickey, Petrosino, Pellegrino, Goldman, Bransford, Sherwood, and CTGV, 1996). The Mars Mission Challenge video visually suggests the wide variety of factors involved in planning and carrying out a human mission to the planet Mars. The video was created with the purpose of facilitating problem generation.

Once the problem generation is completed, the learning environment further supports student inquiry into solving their complex problems as they engage in sustained, project-based instruction over an 8-10 week period of time. The Mission to Mars Learning Cycle (see Figure 1.0), is an instructional sequence which emphasizes opportunities for students to engage in intentional learning through specific instructional sequences and by incorporating classroom based research on instructional activities to maximize student learning such as Minstrell's (1989) use of Benchmark's and Palincsar and Brown's (1984) reciprocal teaching techniques. Included in the instructional sequence are several of assessments (Stiggins, 1995) incorporating formative, reflective and performance based assessment opportunities.

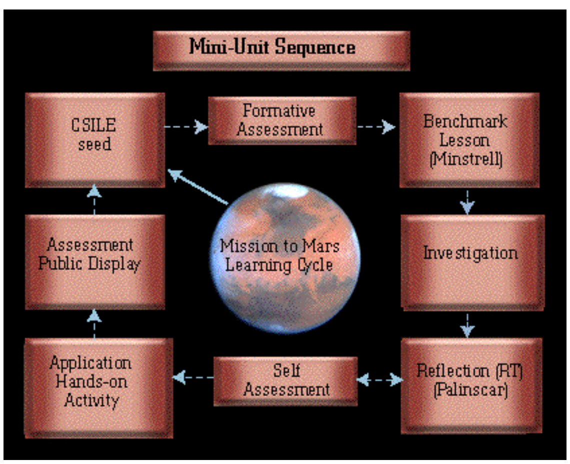

Figure 1.0 Mission to Mars Learning Cycle

Previous Research

The Mission to Mars learning environment has provided the context for a number of investigations into the incorporation of modern theories of learning to the classroom including problem generation, (Hickey, Petrosino, Pellegrino, Goldman, Bransford, Sherwood, and CTGV, 1994) problem posing, (Chuck), coordination of technology in a classroom setting (Weeks), the role of outside experts (Petrosino, 1996), and children's use of experimentation strategies using hands-on activities (Petrosino, 1997). In addition, Brophy (1997) has developed an video indexing tool especially for the Mission to Mars environment.

As each cycle of research, reflection and revision occurs with the Mission to Mars unit, we, as researchers, gain opportunities to modify the instructional sequence to provide a more effective learning environment. In this manner, we engage in the reflexive nature of research and practice (Glaser, 1994) as we work with teachers, students and fellow researchers to provide an effective instruction informed by modern learning theory which can provide sustained inquiry in a project-based classroom.

A Principled Approach to the Design of CSCL Tools: The Mission to Mars Webliographer

To guide our discussion on the development of the Mission to Mars Webliographer, we use a framework presented by Koschmann, Kelson, Feltovich, and Barrows (1996). This framework has been useful for our team as we attempted to proceed in a principled manner through the design process of developing a new technology for our classrooms. The framework comprises four steps. First, a model of effective instruction and design goals needs to be articulated. Second, how may technology assist in light of current practice. Third, the creation of a mutually beneficial marriage of instruction and technology in which the needs of the classroom are met by the existing technology. Fourth, flexibility and accommodation through creative use must be emphasized to support variability across classrooms and opportunities for the CSCL tool to "co-evolve" with practice (Suchman and Trigg, 1991).

We will begin with a brief account centering on the development of the general Webliographer format. Next, we will examine each of the four components of Koschmann, Kelson, Feltovich, and Barrows' (1996) framework in more detail. Finally, we will present some initial findings from our research.

Introduction

Perhaps the greatest advantage that the Mission to Mars Webliographer provides is easy access to any set of Internet resources related to the project under

[1]For a more complete description of the Mission to Mars unit see Petrosino (1994) and Lamon et al. (1996).

investigation by the students. While it would be possible for curriculum specialists to create a set of web pages using any of several easy to use tools for web page development, it is not an easy task to manage such a site with dozens or hundreds of links.

Webliographer (Pfaffman, 1997) was first envisioned in reaction to the great number of web pages which comprise little more than links to other resources. Also, many schools have a person who spends hours dredging through the web finding fantastic resources who then shares them by printing out the pages or e-mailing them to people. While these methods of communication have their merits, they lack convenient means for archival, retrieval, or auditing their use. With static web pages it is also difficult for multiple people to work together to develop pages since one person's edits may wipe out another person's work.

Webliographer solves these problems by keeping its information in a database rather than in static HTML files. When a page is requested its contents are produced dynamically through database lookups. This allows multiple views of the web resources and automatically provides means for searching. To the user, Webliographer looks like any other web page or search engine. To add a URL to the database (or web site, depending on one's view), one simply fills out a form with a URL, descriptions (one word, one line, and short paragraph), and a topic (see figure 2.0). The URL is then immediately available for searching and browsing.

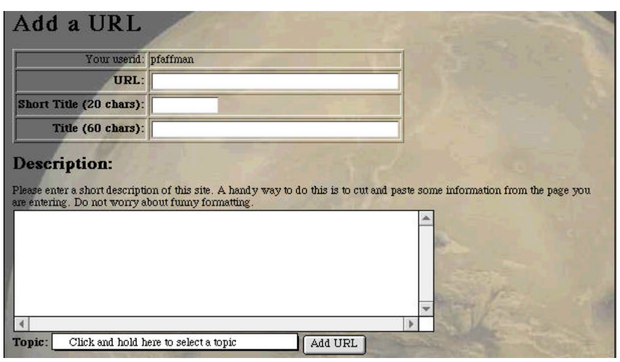

Figure 2.0 This form is used to add a URL, its description, and topic to the database.

Methodology

The methodology used to conduct this research has been one in which Lincoln and Guba (1985) describe as naturalistic inquiry. The data corpus consists of videotapes and field notes taken over the span of two semesters from three general sets of activities: small group work, one-on-one interviews with each student and the students entries to the Mission to Mars Webliographer database.

The researchers often engaged in informal questioning during ongoing project-based research. In addition, the researchers took field notes in order to document the instructional activities. These notes were written and reviewed and then discussed with the classroom teacher in order to triangulate the data. Finally, a video camera was placed in the classroom to record students' interactions during whole-class and some small-group activities. The following discussion utilizes the findings of this research.

First Step: A Model of Effective Instruction and Design Goals

Collins, Greeno, and Resnick (1994) describe a shift in perspective in educational psychology from teaching to learning. They explain that while the change is subtle it nonetheless reflects a move away from an information transmission view to a constructivist view of education. In addition, another shift they see is the recognition that learning and work are not separate activities. In fact, learning takes place both in and out of school (Resnick, 1987), and students activity in school is a form of work (see also Hmelo and Guzdial, 1996).

In their discussion (see summary Table 2.0), Collins, Greeno and Resnick (1994) describe three observable functions which distinguish most learning environments: (a) participation in discourse (what learners do); (b) participation in activities (instruction that teachers model); and (c) presenting examples of work to be evaluated (assessment). These functions are all essential to effective learning. Traditional schooling has placed emphasis on the information transmission, training, recitation and testing components while more innovative and contemporary learning environments like Mission to Mars have placed emphasis on the communication, problem-solving and performance characteristics.

Table 2.0 Learning Environments (from Collins, Greeno, & Resnick; 1994)

General Function	Specific Kind	Characteristics	Examples
Discourse Participation	Communication Environments	learners actively construct goals, problems, meanings, information, and criteria of success	Discussion, Argumentation, Inquiry, Brainstorming
	Information Transmission Environments	learners receive information	Reading, lectures, broadcast television and radio, videotape, film and interactive video
Activity Participation	Problem-Solving Environments	learners work on projects and problems	Apprenticeship, projects, simulation environments, video and computer technology
	Training Environments	learners practice exercise to improve specific skills and knowledge	Drill, rehearsal, practice (RT), programmed instruction
Evaluation	Performance	learners perform for an audience	Performances, not contests
	Recitation and Testing	learners demonstrate their ability to work problems or answer questions	Memorize, tests to find out what is learned

Research in education and cognitive science like that of Collins, Greeno, & Resnick (1994) has provided guidance for what is needed for facilitating effective instruction and overcoming the challenges in project-based instruction, which focuses on complex, ill-structured domains (i.e., trip planning). The result is that we seek to develop classroom learning environments which promote communication environments over information transmission environments, problem-solving environments over training environments and performance assessments over more traditional forms of recitation and testing evaluations. While every classroom will have some aspects of the entire learning environment proposed by Collins, Greeno and Resnick, the Mission to Mars environment has attempted to implement the characteristics consistent with extraordinary achievement for all students, not just a select few (Bruer, 1993; Resnick, 1987)

Second Step: How May Technology Assist

After the initial showing of the Mission to Mars video, students are asked to generate an exhaustive list of potential problems to research in order to plan and complete a human mission to the planet Mars. Once this step is completed, the students, with guidance from the teacher, sort their questions into categories, one for each research group (making up 3 to 4 students). Over the course of the last five years of implementation, we have found recurring categories which closely mirror the various disciplines that students in the sixth grade encounter. Thus, the groups formed were (1) Medical Officer (Human Factors), (2)Supply Officers (Equipment/Food), (3) Engineering (Navigation/Propulsion), (4) Environmental Preservation Team (Spacecraft Environment), (5) Spacecraft Design, and (6) Away Team (Surface Exploration). The student-generated categories closely resembled these optimal categories. In addition to being familiar to the students, these categories were relatively exhaustive, covering major areas of concern for middle school curriculum.

Over the next two months, these research groups spend approximately two class periods a day attempting to become classroom experts in their own content area. They use trade books, news articles, instructional materials from NASA, informative CD-ROM's, and library resources to thoroughly research their area. After summarizing their findings, the specific content-specific groups disband and the class reforms into jigsaw groups. Each new jigsaw group now has an "expert" from each of the initial content-specific groups. In this manner, every child "expert" shares the information obtained previously to the new jigsaw group. These new groups engaged in an ill-structured knowledge domain (Spiro, Coulson, Feltovich, & Anderson, 1988) which centers on planning an expedition to the planet Mars.[2]

[2] With some teacher guidance, student generated topics and discussions often overlap with existing curriculum objectives. To date, such curricula concerns have presented little trouble to our teachers and administrators.

With the advent network connections to the World Wide Web, students and teachers began utilizing the Web for research concerning the Mission to Mars unit. However, after initial observations, it became clear that students were often frustrated by available search engines and the teachers noticed a growing number of students off-task during what previously had been very productive research time.

Teacher 1: *I think it would be really helpful to be able to share bookmarks quickly within the building. Kids left to search on their own...they waste lots of time. They need a starting point. They (students) just don't know how to construct efficient or effective searches.*

While the use of "Bookmark" features were useful, such tools were limited to individual computers. There was little opportunity to share favorite sites with others and teachers felt especially isolated from the process.

Teacher 2: *What would be really helpful for me is a couple of things like some clearinghouse information about good sites on the Internet for our curriculum...that would really cut down a lot of time. I want the kids to have the bookmarks available without having to spend an hour and a half surfing around on the net and still not find what they need.*

Clearly there was a need for a tool to assist the classroom teachers in coordinating the vast resources of the Internet. In the next section, we will review the marriage of the available technologies with the instructional needs of the classroom.

Third Step: A Mutually Beneficial Marriage of Instruction and Technology

The third step in Koschmann et al's (1996) process is the development of a specification based on both the instructional requirements of the setting and the known capabilities of the proposed technology (see Table 2.0).

According to Koschmann et al. (1996), technology must be adapted to meet the instructional needs rather than the technological capabilities, or the design will regress into one that is technology-driven. In the current project, the technology that was available to the children (e.g., electronic mail, Local Area Network, CD-ROM, Internet) could only accommodate some of the requirements of the learning environment. There was a need for additional technologies that would not only be consistent with the goals of the Mission to Mars learning environment (see discussion of Collins, Greeno, and Resnick, 1994) but allow for exciting opportunities for the incorporation of the vast amount of resources available on the World Wide Web (Owston, 1997). The need for a tool to assist the classroom in the use of Internet resources for the Mission to Mars unit was made readily apparent through our discussions with the classroom teachers.

Table 3.0 Analysis of Instructional Requirements and Technological Capabilities

Instructional Requirements of the Mission to Mars Learning Environment	Capabilities of the Technology (Internet)
• Sustained Inquiry • Sharing of Information • Demonstration of Proficiency • Meaningful Problems • Public Displays of Knowledge	• Availability of Information • Cost Effectiveness of Instructional Resources • Ease of Publishing • Interactive Nature • Student/Teacher Excitement

Teacher 2: *I need something to save time...like, if you find a good site, I want to be able to load it somehow on the disk and just take it to any computer in the building and open it (WWW site) up so you have the site without having to type in and make hand copies of all those web pages.* ***That*** *would be really helpful...that would cut down a lot of time.*

Instead of "somehow loading it onto a disk", the Mission to Mars Webliographer allows a site to become a permanent part of the opening page. We took the needs of the teachers seriously and attempted to construct a technology for their use that perhaps they did not even realize was capable. However, without their initial input and discussions, we would never have realized the opportunity for how technology could support their classroom practice. The following section discusses what actually happened once the Mission to Mars Webliographer was put into active use in the classroom.

Fourth Step: Flexibility and Accommodation Through Creative Use

The fulfillment of the challenges placed before us for the effective use of the World Wide Web with the Mission to Mars unit was the creation of the Mission to Mars Webliographer (see Figure 2.0). This software has four features which allow for the optimal use of the Internet in a project-based classroom learning environment. First, the Mission to Mars Webliographer offers an opportunity for a community to create a shared database of useful sites that were found by any member of the research community (student, teacher, outside experts). Second, each entry into the Mission to Mars Webliographer contains a short description of the web site, its address, plus an opportunity to place a review of the site for future users (see Figure 3.0). In this manner, the Mission to Mars Webliographer creates a lasting record of student research and opportunities to build upon previous members investigations.

Third, since the site is context bound, students focus on their research for a greater amount of time and with fewer disruptions. During a monthly professional workshop, a number of teachers expressed excitement over the software's development and have since incorporated the Mission to Mars Webliographer in other project-based units unrelated to the Mission to Mars unit. Lastly, perhaps the most important aspect of the Mission to Mars Webliographer is that it allows for multiple sites to share the same information. This has been especially useful with the Mission to Mars unit since it is now in five schools [3].

As we have previously noted with our teacher interviews, the issue of "saving time" occurs again and again throughout the data. For instance, here is a discussion with two students describing the Mission to Mars Webliographer to a "visitor" (actually, a fellow researcher) during a workshop:

S1: *It's doing all different web sites into one web site so you don't have to go searching around the web for everything*

R1: *Did you do all that?*

S1: *No, most of that was done already. But if you need to go to other web sites you got Yahoo and Alta Vista right here [points to top of screen], so you can go to either one of them.*

S2: *You don't have to search through the whole web site and waste time*

S1: *Yeah, this is a real time saver. it's like loading a bunch of other web sites so you don't waste class time finding them.*

Once the Mission to Mars Webliographer was demonstrated, the teachers were very encouraging. For instance, the following transcript reveals the need that existed for an effective tool to organize Internet resources and for the sharing of useful sites.

Teacher 1: *I have talked to other teachers in the building and have told them about Webliographer and they are just "You're Kidding!"...because, there are a lot of [teachers] that know that several of us have already gone and done research and are now further ahead in the research than they are. And now they just found out that all our links and connections are available to them too...they are really excited about it.*

Teacher 2:: *But I'll tell you what, the morning that I started this research and I went over there (to the computer) and pulled [Webliographer] down and there they all were [relevant Mission to Mars URL's], I almost passed out! I just went, "oh, this can't be...it's too good", so I stopped everything and showed all the kids.*

Furthermore, the teachers were very aware of the availability of the Mission to Mars Webliographer resources for their own and others use, independent of time or place. They were most impressed with the availability and permanence of the database and the degree to which it helped the students in their research.

Teacher 3: *We've spent several thousands of dollars to go to workshops and get help in our research and to find information that we needed to support and help us with the Internet...I mean, there's nothing out there. What you have accomplished is far better than any software that I've had or any documents that have been handed to me...once it's in there it's available to everybody.*

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[3] Actually, the Mission to Mars Webliographer may be accessed by anyone with access to the WWW (http://relax.ltc.vanderbilt.edu/mars/). However, to actually publish a URL or give a review of a site, a person must have a password. In this way, we provide a level of security for the database and assure that all information contained on the Mission to Mars Webliographer is appropriate for middle school children.

Figure 3.0 Mission to Mars Webliographer Main page. Categories are on the far left (next to the bullets) and relevant URL's are to the right. Notice the availability of direct searches available for both Yahoo and Alta Vista as well as search availability of the Mission to Mars Webliographer database as well. This allows maximum access of Internet resources. When a student clicks on "Surface Features", Figure 3.0 appears.

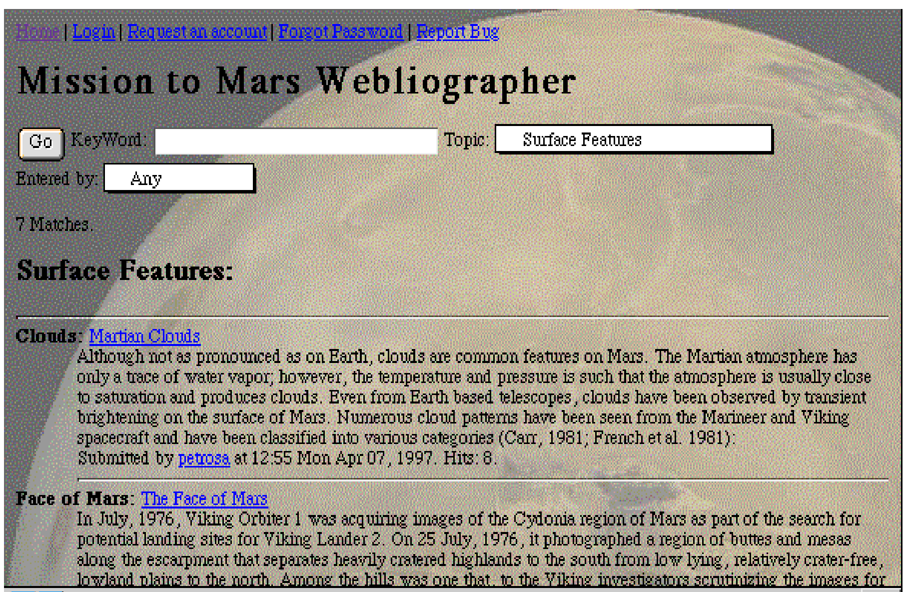

Figure 4.0 Once the student clicks on "Surface Features" form the Main page, a list of relevant web sites is produced which contain brief descriptions of the site, when it was last accessed, and who posted the URL to the Mission to Mars Webliographer. Passwords are needed for posting information although anyone may access the web site.

Concluding Remarks

According to Krajcik, Blumenfeld, Marx, and Soloway (1996), one major key to promoting project-based science is to find ways to support teachers as they change from more traditional models of instruction to those which stress students' transformation of ideas. Clearly, the use of the Internet and its many resources can be of great use to a classroom committed to project-based instruction. We believe that in the hands of able teachers, the Web can play a prominent role is assisting students in critical thinking, problem solving, written communication and the ability to work collaboratively (Uchida, 1996), provided there is accommodation between the instructional requirements of the classroom environment and the known capability of the existing technology.

In the Mission to Mars unit, technology does not simply provide a modern format for practicing basic skills, as it does in many classrooms (Secules, Cottom, Bray, and Miller, 1997). Students use technology to gather information not found in their school libraries, and write research reports. They create multimedia supports for oral presentations (public displays of knowledge), and discuss their findings with other researchers in their classroom and across the country. Being part of Schools For Thought (Lamon et al.), a large national project, has provided the necessary institutional support for this undertaking. Having the opportunity to assist teachers and students in the development of technology to assist in the utilization of the World Wide Web has been both challenging and rewarding. Using the theoretical perspective of Koschmann et al. (1996) to guide out thinking along the process has been invaluable.

References

Barron, B. J., Schwartz, D. J., Vye, N. J., Moore, A., Petrosino, A. J., Zech, L., Bransford, J. D., and CTGV. (in press). Doing with understanding: lessons from research on problem and project-based learning. *Journal of Learning Sciences*. J. Kolodnor (Ed.).

Brophy, S. P. (1997, April). Managing ill-structured problem spaces within video-based anchors. Paper presented at the Annual Meeting of the American Educational Research Association. Chicago, IL.

Bruer, J. (1993). *Schools for thought: A science of learning in the classroom*. Cambridge, MA: MIT Press.

Collins, A., Greeno, J.G., & Resnick, L.B. (1994). Learning environments. In T. Husen & T.N. Postlewaite (Eds.*), International encyclopedia of education* (2nd ed.). Oxford, U.K.: Pergamon.

Czarnik, J. C., and Hickey, D. T. (1997, April). Problem generation in constructive learning environments. Paper presented at the Annual Meeting of the American Educational Research Association. Chicago, IL.

Glaser, R. (1994). *Application and theory: Learning theory and the design of learning environments*. Paper presented at the 23rd International Congress of Applied Psychology, Madrid, Spain, July 1994.

Goldman, S. R., Petrosino, A., Sherwood, R. D., Garrison, S., Hickey, D., Bransford, J. D., & Pellegrino. (1996). Anchoring science instruction in multimedia learning environments. In S. Vosniadou, E. DeCorte, & H. Mandl (Eds.), *International perspectives on the design of technology-supported learning environments*. Hillsdale NJ: :Lawrence Erlbaum Associates.

Hickey, D. T., Petrosino, A. J., Pellegrino, J. W., Goldman, S. R., Bransford, J. D., Sherwood, R., and CTGV (1996). The Mars mission challenge: A generative, problem-solving, school science environment. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *Psychological and educational foundations of technology-based learning environments.* Springer-Verlag.

Hmelo, C. E., and Guzdial, M. (1996). Of black and glass boxes: Scaffolding for doing and learning. In D. Edelson & E. Domeshek (Eds.), *International conference on the learning sciences*, 1996. Charlottesville, VA: Association for the Advancement of Computing Education.

Koschmann, T., Kelson, A.C., Feltovich, P. J., and Barrows, H. S. (1996). Computer-supported problem-based learning: A principled approach to the use of computers in collaborative learning. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 83-124). Hillsdale, NJ: Lawrence Erlbaum Associates.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., and Soloway, E. (1994). A collaborative model for helping teachers learn project-based instruction. *Elementary School Journal*, 94, 483-497.

Lamon, M., Secules, T., Petrosino, A. J., Hackett, R., Bransford, J. D., and Goldman, S. R. (1996). Schools for thought: Overview of the project and lessons learned from one of the sites. In L. Schauble and R. Glaser (Eds.) *Innovations in learning: New environments for education.* Mahwah, NJ: Lawrence Erlbaum Associates.

Lincoln, Y. S. & Guba, E.G. (1985). *Naturalistic Inquiry*. Sage Publications: Newberry Park, CA.

Minstrell, J. (1989). Teaching science for understanding. In L. Resnick and L. Klopfer (Eds.), *Toward the thinking curriculum: Current cognitive research.* 1989 Yearbook of the Association for Supervision and Curriculum Development (pp. 129-149). Washington, DC: Association for Supervision and Curriculum Development.

Owston, R. A. (1997). The world wide web: a technology to enhance teaching and learning? *Educational Researcher*, Vol(26), No.2.

Palinscar, A. S., and A. L. Brown. (1984). Reciprocal teaching of comprehension—Fostering and monitoring activities. *Cognition and Instruction*, Vol(1) No.2, pp.111-175.

Petrosino, A. J. (1997, April). Authentic experience within investigative activities: The role of reflection in the learning environment. Paper presented at the Annual Meeting of the American Educational Research Association. Chicago, IL.

Petrosino, A.J. (1996, August). The role of content expertise in the learning community. Paper presented at the International Conference on the Learning Sciences, 1996. Evanston, IL.

Petrosino, A.J. (1995). *Mission to mars: An integrated curriculum.* Nashville,TN: The Cognition and Technology Group at Vanderbilt University.

Pfaffman, J. A. (1997). Webliographer: A Community Web Database. [Online.] Available: http://relax.ltc.vanderbilt.edu/webliographer/notes/notes.html.

Resnick, L. (1987). Learning in school and out. *Educational Researcher*, 16(9), 13-20.

Scardamalia, M., Bereiter, C., & Fillion, B. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences*, 1, 37-68.

Secules, T., Cottom, C., Bray, M. and Miller, L. (1997). Creating schools for thought. *Educational Leadership.* Vol(54). No.6.

Soloway, E., Krajcik, J. S., Blumenfeld, P., and Marx, R. (1996). Technological support for teachers transitioning to project-based science practices. In T. Koschmann (Ed.), *CSCL: Theory and Practice of an emerging paradigm* (pp. 269-305). Hillsdale, NJ: Lawrence Erlbaum Associates.

Spiro, R. J., Coulson, R. L., Feltovich, P. J., and Anderson, D. K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In *The tenth annual conference of the cognitive science society* (pp. 375-383). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stiggens, R. J. (1994). *Student-centered classroom assessment.* Merril: Prentice Hall: New York.

Suchman, L., & Trigg, R. (1991). Understanding practice: Video as a medium for reflection and design. In J. Greenbaum & M. Kyng (Eds.), *Design at work: Cooperative design of computer systems* (pp. 65-90). Hillsdale, NJ: Lawrence Erlbaum Associates.

Uchida, C. (1996). *Preparing students for the 21st century.* Arlington, VA: Association of School Administrators.

Weeks, K. W., Talwalker, S. B., and Evertson, C. M. (1997, April). The orchestration of complex learning environments: A case analysis. Paper presented at the Annual Meeting of the American Educational Research Association. Chicago, IL.

Notes

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