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Navigating the World Wide Web: The Role of Abductive Reasoning¹

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Navigating the World Wide Web: The Role of Abductive Reasoning

Abstract

In this paper we describe some of the outcomes of two studies in which subjects think aloud while navigating information to be found on the WWW. In the first study, university students were asked to find information relevant to questions they selected from a list we provided, questions like “Does the death penalty deter violent crime?” or “What is the best breed of dog for you?” In the second study, mathematics educators (elementary and secondary teachers) were asked to navigate the website of a professional association to find information pertinent to their classroom. We classified the navigational strategies and inferential reasoning used by the subjects according to a model of reasoning developed by Shank and Cunningham (1996). The data show that abductive reasoning dominates in the web context to an extent not well appreciated in educational circles. Implications for instructional design are explored.

Navigating the World Wide Web: The Role of Abductive Reasoning

This paper describes a program of research that inquires into the processes that people use when they navigate the World Wide Web (WWW) or hypermedia documents to make decisions and acquire new skills. Most models of learning and cognition are not well suited for open-ended resources like the WWW. In traditional instruction, where we are able to specify the material to be learned and codify it in a format that we can then make available to the learner, effective learning and teaching are largely a matter of clear communication – from the teacher or instructional materials to the learner. Basically, knowledge and skills are presented or demonstrated to students for their subsequent internalization and use. They are told (or permitted to discover under controlled conditions) what they need to know and then required to test that knowledge in new or supplied contexts. This "received knowledge" view relies heavily upon inductive and deductive reasoning skills on the part of the students; that is, their learning is predicated on their ability to understand the knowledge or problem identified, and then to acquire and test the means provided to apply the knowledge or solve the problem.

Increasingly, however, teachers and learners have made use of open-ended resources like the WWW. We believe that such resources require additional skills for both teachers and learners that must be identified and supported. Skills in inductive and deductive inference are insufficient - learners are typically information seekers, not the end point of a communicative act. They are energized by "problems" that have emerged in the course of their learning or from their everyday experience. Their task is as much to identify and make sense of the "problem" as it is to discover solutions. As we move into the Information Age and are inundated by increasing volumes of information, the need for reasoning skills that go beyond acquiring and applying knowledge is ever more evident.

A major feature of the research described here will be to adopt a model of reasoning derived from the writings of C. S. Peirce (1931-1958). Peirce proposed three modes of inference rather than the traditional two: abduction, deduction and induction.

Here is how Peirce describes the three modes:

Deduction is the only necessary reasoning. It is the reasoning of mathematics. It starts from a hypothesis, the truth or falsity of which has nothing to do with the reasoning; and of course its conclusions are equally ideal. The ordinary use of the doctrine of chances is necessary reasoning, although it is reasoning concerning probabilities. Induction is the experimental testing of a theory. The justification of it is that, although the conclusion at any stage of the investigation may be more or less erroneous, yet the further application of the same method must correct the error. The only thing that induction accomplishes is to determine the value of a quantity. It sets out with a theory and measures the degree of concordance of that theory with fact. It can never originate any idea whatsoever. No more can deduction. All the ideas of science come to it by way of Abduction. Abduction consists in studying facts and devising a theory to explain them. Its only justification is that if we are ever to understand things at all, it must be in that way. (Peirce, 1955, p. 150)

Shank & Cunningham (1996) have extended this model of reasoning by linking it with Peirce's classification of signs. The derivation is too technical to go into detail here, but we have identified six modes of abduction, three modes of induction and a singular mode of deduction. We will sketch out a brief description of each mode, building upon these descriptions to include an ongoing concrete set of examples. Each is named for the product or outcome of the inference (We include Peirce's classification in parentheses for those who wish to follow the derivation). Any particular inference will likely be a mixture of one or more of these, but usually one mode predominates.

1. Hunch (or Rhematic Iconic Qualisign). This type of inference deals with the possibility of a possible resemblance. A more concrete way to characterize this type of reasoning is to describe it as reasoning in order to determine the possibility that our initial observations might serve as a source of possible evidence. For instance, an archeologist might guess that she should examine the banks of an ancient river bend, because she might possibly find something that might possibly be an artifact.

2. Symptom (or Rhematic Iconic Sinsign). This type of inference deals with possible resemblances. Here we have the case where we are trying to decide whether or not some actual observation has enough properties to be considered as some case. Is our observation a symptom for the presence of some more general phenomenon? A symptom is a sign whose action is ongoing in the present. For instance, suppose our archeologist finds a smoothed stone. It is not immediately clear whether or not the smoothness is natural or man-made, and so she has to make an inference. In these inferences, we often find a dependence on prior experience is involved.

3. Metaphor/Analogy (or Rhematic Iconic Legisign). This type of inference deals with the manipulation of resemblance to create or discover a possible rule. For example, suppose our archeologist is having trouble reconciling the artifacts she is discovering with the current theories of the social structure of this culture. Thinking through how this discrepancy might play out in a contemporary culture may help her imagine a potential resolution.

4. Clue (or Rhematic Indexical Sinsign). This type of inference deals with possible evidence, whether or not our observations are clues of some more general phenomenon. A clue is a sign that indicates some past state of affairs or circumstances, so determining whether something is a clue is an act of detection. For example, our archeologist discovers a mound of pottery shards next to a number of smooth stones. Is there any connection between the two, or is it just a coincidence? In order to make a judgment, she looks at the shards and looks at the smooth stone, searching for evidence of some physical connection. Were the stones used, for some reason she does not yet know, to shatter the pots?

5. Diagnosis/Scenario (or Rhematic Indexical Legisign). This type of inference involves the formation of a possible rule based on available evidence. A more concrete way to characterize this type of reasoning is to describe it as reasoning in order to build possible diagnostic judgments or plausible scenarios from the body of clues. For instance, our archeologist notes that the shattered pots are all placed in a shallow pit, and there are other smooth stones organized around the edges of the pit. She then starts the process of assembling these individual observations no longer as observations, but now as potential scenarios. Perhaps the pots were broken as part of a burial ritual.

6. Explanation (or Rhematic Symbolic Legisign). This type of inference deals with a possible formal rule, as reasoning in order to form a general plausible explanation. Our archeologist wants more than a single diagnosis or scenario. She wants a rule that can summarize many separate pieces of evidence, and a number of alternative scenarios, into a single coherent explanation that has the additional advantage of serving as the basis for meaningful insight. That is, a good explanatory hypothesis does not just explain the obvious. It directs us toward the less obvious, and sheds light on areas once seen as unclear or unconnected. Explanations then become fodder for inductive testing and deductive elaborations.

7. Deductive reasoning (or Argument Symbolic Legisign). This mode is formal reasoning where a necessary conclusion is reached based upon formal rules. Here our archeologist might link hypotheses, such as the one mentioned above concerning broken pots and a burial ritual for further inductive and abductive reasoning. For instance, might we predict that human remains would be found at the same site? Or are some burial rituals performed at sites far removed from the actual remains?

8. Identification (or Dicent Indexical Sinsign). Our first category of inductive inference tests for actual evidence of a particular thing. Here we are testing whether our observation is an instance of X, where X is something already assumed. In more scientific parlance, this might be called construct validation. Our archeologist might test whether various sites that she has sampled have enough characteristics in common to confirm her abduction that the breaking of pots was a burial ritual.

9. Prediction (or Dicent Indexical Legisign). This mode of induction reasons from actual evidence of a probable rule. When constructs are linked in some causal or covariate relationship, our observations can be used to test the veracity of the relationship. In formal settings this might be referred to as hypothesis testing. For example, our archeologist might test a prediction that another culture with similar social structures would have a similar ritual

10. Model building (or Dicent Symbolic Legisign). If our inductive tests lead to a probable conclusion based upon a rule or set of rules, we are building models. When rules form a coherent whole and create a structure from which actual experience can be tested, then habits, models or worldviews emerge. A common scientific framework for this sort of inquiry is called convergent validity. Our archeologist can begin to empirically build the kinds of models that have explanatory value across a variety of cultures.

It may be noted that each of the six modes of abduction deal with potential or possibility, each of the three modes of induction deal with actuality, while deduction focuses on rules and regulation. It is the modes of reasoning that emphasize possibility that are so important in successfully using the WWW. On the Web, we are following hunches and looking for clues, building scenarios and coming up with tentative explanations. We have to sharpen our skills to learn which symptoms are important or to be trusted and which are irrelevant or red herrings. Abduction alone, of course, is not sufficient. Ideas must be linked by reason to other ideas and tested. In its current form the WWW may be less well suited for induction and deduction, as described above, but there is nothing inherent in the Web that prevents it from serving those modes.

Most research on inference and reasoning focuses on induction and deduction. Abductive processes, if they are discussed at all, are often dismissed as unscientific or unsystematic, a phase that must be gotten past in order to

bring to bear the powerful methodologies of induction and deduction¹. We, like Peirce, believe that scientific reasoning is also a process of following hunches, creating scenarios, following up on clues, proposing tentative explanations, and so forth. These inferential moves can be every bit as systematic and trainable as syllogistic reasoning. The WWW provides a marvelous opportunity to study the varieties of abduction in action and the work proposed here should provide insights into learning from the WWW in particular as well as scientific reasoning in general.

In this paper we describe some of the outcomes of two studies in which subjects think aloud while navigating information to be found on the WWW. In the first study, university students were asked to find information anywhere on the WWW relevant to questions they selected from a list we provided, questions like “Does the death penalty deter violent crime?” or “What is the best breed of dog for you?” In the second study, mathematics educators (elementary and secondary teachers) were asked to navigate the Website of a professional association to find information pertinent to their classroom.

Method

Study 1

Participants and Data Collection. Ten paid participants were solicited from a large Midwestern university. Each participant worked individually on the Web in the presence of a single researcher. Participants were audio and video-taped as they searched for information on the WWW. Think-aloud protocols (Ericsson & Simon, 1984) were recorded for the duration of the time spent on the WWW. A mediator interface was connected between the computer monitor and a VCR to video record the mouse movements, searches, and Web sites visited. In addition, the URL addresses of each Website visited were recorded by a software program. The browser used for all Web sessions was Netscape Navigator. Participants were allowed to use all aspects of the Web they were familiar with, including bookmarks, search engines, etc. Entrance questions were asked at the initial session and debriefing questions were asked at the end of each session on the Web. Each participant worked for a total of approximately 8 hours on the Web, averaging 1-2 hours per session. The audio tapes were transcribed by the observer and transcripts were given to the participant to review and clarify. Participants were also shown the video tape of their session and asked to clarify or comment on any aspect of it.

Procedures. The participant was asked a series of entrance questions regarding experience and ability of using the Web. The participant was then instructed in procedures for verbalizing thoughts and actions. Next, the Web user chose a question from a group of 10 potential problem-solving tasks. Some sample topics include 1) how to reduce school dropouts, 2) does the death penalty deter violent crimes 3) find the best breed of dog for you, 4) plan the best vacation itinerary for the lowest price. In each session, the participant completed a new problem-solving task. The Web user continued to think aloud for the duration of the session, while the researcher silently observed. The participant decided when enough information had been gathered to conclude the task. At the end of the problem-solving session, the researcher asked the participant questions to reflect upon the Web experience. At the beginning

¹ Noddings (1999) wonders why, if abduction is so important, “has it been almost ignored for so long?” We might point out that bacteria, as a source of infectious disease, were ignored for a long time as well.

of the next session, the participant was shown the transcript and video from the previous session and asked to clarify or elaborate on any part.

Study 2

Participants and data collection. Participants in this study were part of a project to test the usability of an electronic version of the National Council of Teachers of Mathematics (NCTM) Standards 2000. NCTM is the world's largest organization of mathematics teachers, with over 110,000 members. In 1989, NCTM broke new educational ground with its release of the *Curriculum and Evaluation Standards for School Mathematics*. That document, together with its successors (*Professional Standards for Teaching Mathematics*, 1991, and *Assessment Standards for School Mathematics*, 1995) launched the modern standards movement in K-12 education, by providing a vision of the content and pedagogy for school mathematics. Beginning in 1996, the Standards 2000 project was initiated to update the NCTM Standards for the year 2000. An electronic format for Standards 2000, to include text and hypermedia illuminations that make full use of available technologies, was under development at the time of this study. The Website was made public in April of 2000 (<http://standards.nctm.org/>). We recruited and paid members of the target user groups (elementary and secondary teachers, administrators, pre-service teachers, etc.) to use the Website while seated in a specially configured usability laboratory, a standard two-room facility including testing and observation rooms separated by one-way glass. The video, audio, and computing equipment were configured to allow the observation, recording, and editing of data, including a scan-converted image of the participant's computer screen (800x600 resolution) with a small "picture-in-picture" image of the individual taken from the ceiling camera in the corner of the room. Sessions lasted from 1-2 hours.

Procedures. Participants first answered a series of questions concerning their familiarity with the WWW and with NCTM. The participant was then instructed in procedures for verbalizing thoughts and actions. They were asked to make use of the Website as if they had been asked by a colleague or administrator to complete a realistic task (construct a lesson plan, write curricula, gather resources for a demonstration, etc.) of their own choosing. Participants continued to think aloud for the duration of the session, while the researcher silently observed. When the participant decided enough information had been gathered or they were too frustrated to continue, the task was concluded. The researcher then asked the participant follow-up questions to reflect upon the Web experience.

Results and Discussion

For purposes of this paper, we will include only one protocol from each study (See Appendix 1 and 2). The difference in the tasks produced remarkably different experiences for the participants.

Study 1

This subject chose to use the WWW to answer the question "What is the best city/town for you to live?" Her first concern is to "narrow a search" (line 4) but is unsure where to begin. Not surprisingly, abduction plays a major role in her search strategies. Like most of our participants, her first impulse is to use a search engine, hoping, we suppose, that the search will produce results that immediately guide her to relevant Websites. She is experienced enough with the Web, however, to know that the keyword(s) on which she searches is crucial if the search is to lead to a manageable result, so she consults the categories used by a popular omnibus Website (Yahoo!). This kind of

preliminary search is very common among our participants with Web experience. We would characterize it as an abductive hunch; that is, the participant is trying to limit her search to Websites that are likely to be productive for her question. Prior experience with both Web tools and with the subject matter in question can greatly improve the productivity of hunches. Another subject, for example, trying to address the question of school dropouts, searched for an on-line sociology class in the hope that the course materials would provide leads (they did!). Inexperienced participants would immediately type one or two words into a search engine (e.g., city) and then react with dismay as the search returned millions of results.

As our participant considers and tries various keywords, she is moving into the domain of symptom – what kinds of things would indicate that a city or town was a good place to live? She considers lifestyle, families, regions as categories from which possible concrete symptoms of good places to live could be identified. She also considers following an analogous path, travel, to see if information about visiting a city would be relevant to living there (lines 18-19).

After some unproductive and frustrating searching, she comes across a Web site that advertises a book of “Top Rated Cities” as part of a Website that offers advice to internationals coming to the U.S. to live. This is closely analogous to what she is after, but in the end she rejects the information because it is too commercialized and too oriented to international. Following another hunch she navigates her way to the Redbook magazine Website (line 72), knowing, we suppose, that Redbook often publishes articles on topics like the best city to live. Here she begins to identify more symptoms (“what they <cities> have in general”, line 76), things that might be relevant to good places to live. These, in turn, become clues to identifying particular cities (line 84) and building scenarios (lines 88-92) that she could then examine for compatibility with other relevant factors in her decision-making about where to live. She reaches her tentative conclusion or explanation in lines 106-111, but we suspect that any actual decision to move to Madison, WI will depend upon further inferential reasoning. Testing the validity of her conclusion by talking with current or former residents would be a clear example of inductive reasoning. Considering whether moving to a colder climate would require her to purchase a new wardrobe is a possible deduction.

This protocol is a good example of a concern that was brought up by nearly every one of our participants - the issue of trust, or the reliability of symptoms and clues (e.g., lines 53 – 62). When a participant opened a Web page, one of their first acts of reasoning was an attempt to abductively analyze the reliability and trustworthiness of that site. Experienced Web surfers looked for signs like the domain of the URL (e.g., .edu sites were more trusted than .com), reputation of the sponsor of the Website, whether or not a product was being sold, whether bibliographies were provided, the credentials of the spokesperson, and so forth. Some participants were reluctant to state a final conclusion to their question based solely on the information found on the Web. Interestingly, many of our subjects expressed a desire to confirm the information in more “authoritative” sources like library books and journal articles.

Study 2

It is almost painful to read this transcript (we can report that it was painful to conduct the session!). The purpose of a usability study is to capture the user’s experience of the Website to learn how to enhance its usability. This

participant's experience was mostly one of getting lost, not finding what she was looking for, dead ends, frustration, and irritation. User-centered design takes as its most fundamental maxim that in cases such as this, it is the fault of the design, not the user. This is clearly the case here. For our purposes, however, the usability of the Website is not at issue. We were interested in seeing what inferential strategies participants would use while navigating a Website specifically designed to provide information on questions such as "What mathematics should second graders know?" or "What are some good ways to teach mathematical problem solving?" Superficially, this task and the one given to participants in Study 1 were the same, but in Study 1 we gave the participant no indication of where to search. Here we asserted (lines 1 and 2) that the Website we had her search DID have some answers to her question. In so doing, we short-circuited the search process such that we see very little in the way of hunches, looking for symptoms, and so forth. As our participant says (line 18) "I'm sure what I'm looking for." Her search is focused exclusively on finding what students in the second grade need to know. Later she illustrates what she is looking for by referring to the standards and principles in her teacher's edition of the mathematics textbook used in her school (lines 117-123). Thus she is treating (and appropriately so) the information on the Website as reference materials to be consulted when needed, like a dictionary or an encyclopedia. Her experience is that these reference materials are hard to search and not well organized by the Website designers. She is inferring that the information she seeks is contained somewhere on the Website and she is seeking ways to access it. In terms of the categories of inference, she is using deduction and induction primarily, seeking authoritative information on the basis of which she can organize her teaching. In such a case, she is absolutely correct that a book may be a much more efficient tool for communicating authoritative information. Those of us in the field of instructional technology often get carried away with our "toys" and assume that because we can put something on the WWW, it makes sense to do so! A book can be quickly scanned and taken in more as a whole. Looking at a Web page sometimes reminds us of looking at a room through a keyhole – you can only see a small part at a time. Having the book in front of you is much more like opening the door and sweeping your eyes across the scene, very effective when you are looking for something in particular and need to see the whole scene in order to decide how to narrow your search. Moreover this participant is much more familiar with and comfortable with her books. She knows precisely where and how to look for the information she seeks, whereas she has yet to master the WWW (line 65) and is not sure she will be able to learn how to use it more efficiently.

Interestingly, this participant treats her excursion into "problem solving" (line 29-50 and *passim*) in much the same way as when she was looking for standards specific to second grade. Rather than using the materials provided to help her get a better idea about what problem solving is and what are the relevant symptoms and clues of effective problem solving, she voices strong opinions about her conception of problem solving and is impatient with the attempts of the Website designers (line 36). Again she is looking for authoritative information on the topic: lesson plans, methodologies for teaching and promoting problem solving, etc. She has very strong views about the importance of problem solving and about what teachers are supposed to do to promote it. She looks for but does not find any information on the Website that will help her teach problem solving and concludes that "...this site doesn't have what I would be looking for." (line 135). Once again deduction and induction dominate.

It is clear to us that there is a serious mismatch between the needs of the participant and the design of this Website. With limited time and Web experience (lines 119 – 122), this participant does not seek an abductive experience where she arrives at some tentative hypotheses or explanations that she can then test out in her classroom. She wants authoritative information and she wants it now! An electronic copy of the NCTM standards with a more sophisticated search engine, or perhaps the book itself, would have met her needs much more directly. The information she sought was, in fact, included on the Website, but as this participant discovered, not obviously. Afterwards we took her through some of the features of the Website and her opinion of it improved, but not to the point, we believe, that she would voluntarily use it. By including more material in the electronic version, the Website designers had unintentionally made the use of the mathematics standards as a reference more difficult rather than less. Whether the Website would support a more abductive use is another study for another day.

Semiotic consciousness and the WWW

Like it or not, the WWW is playing a dominant role in the daily lives of many people. More and more classrooms throughout the world are connecting to the Internet and making use of the WWW as a teaching tool (Webquests, e-pals, synchronous and asynchronous discussion groups, virtual field trips, on-line courses, and so on). Business and industry is likewise incorporating the internet into many aspects of their operation: training, communication, sales, marketing, personnel and so forth. Over half the homes in the United States have access to the Internet and more and more people are using the Internet to perform countless daily tasks. We are becoming inundated as never before with information (and opportunities). Rather than reducing our uncertainties about what the correct solution to a problem might be, this increased access may in fact increase our uncertainties by showing use more options than we can handle (Cunningham, in press). Cunningham (1998) describes the situation this way:

“On the WWW.....we are driven by genuine doubt, curiosity and playfulness to surf the Net, to explore the many communities of discourse and practice found there. We are embodying a process of inquiry and modes of reasoning described many years ago by Peirce, but only now recognized as unique and ubiquitous. The learner is an information seeker, not the end point of a communicative act. As we move through the Information Age and are continually being inundated by increasing volumes of information and patterns of potential significance, the need for reasoning skills, information seeking, and conceptual navigation is ever more evident. Mastering a subject matter becomes the exception rather than the rule. Clear communication about a domain of knowledge or set of skills in anticipation of future application becomes less important than connecting with resources as they are needed to solve a contemporaneous problem. The dominant metaphor of education as efficient communication or knowledge consumption must change to that of the hunter-gatherer”(pg. 834-835).

Like the hunter-gatherer, Web users need to develop the skills of devising useful hunches, identifying trustworthy symptoms and signs, using metaphor and analogy to further one's search, building plausible scenarios and tentative explanations. If, as in the case of our participant in Study 2, the WWW is being used as a repository for authoritative information, then we need to sharpen the users inductive and deductive reasoning. But the WWW is such a dynamic open-ended resource that traditional models of inductive and deductive reasoning do not suffice in explaining a Web user's thoughts and actions. The WWW is not simply a collection of pages and links that users can view and click on, but is equally a larger process of sense-making. The interesting question to be answered in Web

research is not what pages exist on the Web, but what path the user chooses as she searches. At each point on this path the user makes decisions; do I go forward, back, start a new search, follow that link? Each choice takes the person in a new direction that corresponds with what they value and trust. Each person has a previously constructed personal scale of trust, relevance, prior knowledge and so forth that guides their reasoning. As a participant navigates the WWW, they are enacting and constructing their Umwelt (von Uexkull, 1957), their worldview of what is important, what makes sense and what is valued. No one taught our participants which Web pages are better than others, however, they all came into this experience with common understandings of what is regarded as acceptable. The explanation for this lies in our experience. Through our experience in the world we construct our current understanding and knowledge as we interact in our surroundings. Although working individually, every participant's answer to the problem-solving task was guided by a community basis for belief (Lave & Wenger, 1991).

There is a national outcry to provide the WWW in American classrooms and few want to be in the slow lane of the Information Highway. However, little is known about how students actually learn and reason with the WWW. The WWW provides a wealth of information but is not a traditional teaching tool. There is an inherent difference between finding information in the library, and finding information on the WWW. When using the Web, the control and direction of the learning process is shifted to the learner. With the information explosion, the learner cannot be expected to master all the information available on the WWW. Instead, the WWW provides the learner with an opportunity to find their own way, as they problem solve and make decisions that determine their path of learning. The role of teacher changes to that of a supporting role, and the educator must give students that freedom to experience this higher-level reasoning that takes place in the Web.

It must be acknowledged, however, that abductive skills are not only important for using the WWW. We routinely use abduction in our daily lives but don't often accord it the importance it deserves. For example, Cunningham (in press) starts his review of a book on scientific reasoning (Klahr, 2000) with the following hypothetical (but pretty typical) scenario:

Oh good! The mail is here.. Let's see. Catalog, catalog, catalog, advertisement, advertisement, another catalog, Educational Researcher...Hmm...interesting looking piece on translating research to policy. I'll have to look at that. What's this? Looks like a book. Did I order a book? Oh wait, it's from Peggy Bengal at LCHC. I volunteered to review a book for Mind, Culture and Activity. I wonder which one she sent? Oh good, it's the one on discovery process. Maybe there will be some stuff in here on abduction. David Klahr. Hmmm. That's interesting. Isn't he at Carnegie Melon? Did a lot of early work on production systems and problem solving from the Newell-Simon perspective? Oh look, Herb Simon is quoted on the dust jacket "from the forward". Who else? Deanna Kuhn, Paul Thaguard.....boy all these people are pretty hard-core information processing AI types. I wonder why MCA is interested in reviewing this? The publisher is MIT Press so it's likely to be a solid piece of work. Let's look in the index. Any entries for "mind? Culture? Activity? Social? Situated?" Nope. Let's look at the reference list. Simon, of course. Lots of folks from the information processing side. No CHAT people here. Let's go back to the index and look for "discovery." Hmmm, no entry. Isn't that what the book is about? Maybe if I look at "reasoning." No, all it says is "reasons for studying science, 2-7". Let's try "thinking." No? Oh wait, I see an entry for "scientific thinking." Another for "scientific discoveries." And here's one on "studying science,

*different approaches." Maybe this will help me. Ah, one of the approaches is sociological. I'll look at that and see if I can get a better idea of where Klahr is coming from. Let's see, page 8. Skimming..... "this <sociological> approach provides us with important accounts of the context in which scientists work...but at a large 'grain size' with respect to the questions addressed in this book." So he's going to study discovery divorced from context? Uh oh. Look at the next sentence. "Some of this work has taken on a distinctly deconstructionist tone that serious scientists have justifiably denounced..." So any work that brings in cultural and historical factors is too broad or scientifically bankrupt? Skimming... here he says his work is not subject to this criticism "because the work conforms to the same canons of science as the fields <physical and biological sciences> it aims to better understand." Well, that's all the more reason to include the social, the historical, the cultural! Physical and social scientists don't work in a vacuum. Nobody does science in isolation, cut off from those canons he talks about, which were, after all created by scientific communities. **WHY DOES MCA WANT SOMEONE TO REVIEW A BOOK THAT IS SO CLEARLY DISTANT FROM, EVEN HOSTILE TOWARDS, A CHAT PERSPECTIVE???***

Our hypothetical book reviewer uses extensive prior knowledge of academic books to identify places to look for relevant information (dust jacket, title page, table of contents, index) and links that information together to begin to build a plausible scenario about the general approach that will be taken in the book. As he tracks down more specific information (passages, references, etc.) he confirms or revises his initial hypotheses, links those hypotheses with other hypotheses and continues the process until he is satisfied that he has correctly pigeonholed the book. He seamlessly and without much conscious attention shifts back and forth between abduction, induction and deduction. We suspect that our participant in Study 2 is equally as facile with her teacher editions. Where did they learn how to do this? Are these skills that can be taught? We have only just begun to understand this need.

Where is the pedagogy, what are the activities and strategies teachers could use that promote abduction? Cunningham (1992) proposes that a worthy educational goal would be to make semioticians out of all of our students, to promote a semiotic consciousness that will enable them to deliberately and consciously control their inferential strategies. If we follow John Deely (1980, pg. 65) and define semiotics as "reflections upon the role of signs in structuring experience and revealing nature and culture to our understanding," we should be satisfied with nothing less than students who show high levels of such reflective abilities. How do we encourage our students to get productive hunches? To develop criteria for determining the trustworthiness of symptoms and clues? To make productive use of reasoning by metaphor and analogy? Instead of focusing on teaching students to effectively receive information from instructional materials and out of the mouths of teachers, how can we promote the kind of self directed, critically conscious individual that Deely describes? The WWW offers one very powerful environment for doing this, but at this point, we have more questions than answers. We hope you will join us in our "abductive" quest to generate some possible answers.

Appendix 1. Sample Protocol from Study 1

Participant: Female, 20s, graduate student

Question: Best town or city to live/relocate.

1 Well, first of all I'm thinking that I picked that question because it sounds intriguing and
 2 I'm sure there are some sites on the Web that probably, although written from various
 3 perspectives, like tourism boards or something, could be helpful to find on the Web, to
 4 narrow a search. But I'm also thinking at this point what to even begin under. So I'm
 5 just going to go to Net Search and I'm trying to figure out a keyword. I'm going to go to
 6 Yahoo!, 'cause that's the only one I use. As for keywords, first I want to see what titles
 7 they have, what subdivisions, and see if I can get any ideas from here. (scanning titles of
 8 categories). Mmm I really can't tell, I think I am going to look just at the United States at
 9 first....Now these are broken down into states, of course. They have 16 states only, and
 10 notice that Indiana is not one. This is about western lifestyle, I think that is what I really
 11 want. I don't think that this is really helping me ...I think I need to start over and try
 12 and limit it. I'm still stuck on that keyword, I was thinking regions, and then United
 13 States, but that didn't seem to help me too much. And I'm not sure as far as how it (the
 14 search engine) is broken down and how wordy I can get on searching. Like "places to
 15 live," well, maybe I should just try it and see what happens.

16
 17 I'm thinking that maybe lifestyles may get me into regions based on some things I like,
 18 the kind of things I'm into. This is travel again. I'm wondering if I pursue travel if that
 19 will be more sites to see or if that's going to get me into some things about places to live?
 20 Parenting and Families too, I wonder if that is just a... I'm going to go with Parenting
 21 and Families because that has a lot to do with, I have children, and I want to get into
 22 what better areas are for families. This is what I don't like sometimes when I am
 23 searching. Not knowing exactly what I want. It's frustrating.
 24 I'm just reading through here. This is more specific, just for parents and that kind of
 25 thing. I was hoping that it would have something that I could link to. In regards to
 26 OK.... I really don't know what to do. I am going to go to Yahoo! just because I know it
 27 and I know how things come up in it. And I'm just going to start sticking in words like...
 28 that way... and see if I can get anywhere.OK, I'm going to go back again to.... Darn
 29 it, I went to Regions already. I'm going to Regions again, because I said that this might
 30 help me out with the United States, I was here already once.I want to know who is
 31 putting it out, because I tend to be more cynical about what is up here. And critical of
 32 who is writing it and for what reasons. So I tend to think about that.

33
 34 Oh great, there is 299... See now this is really, like I'm ready to just pick a blind choice of
 35 where to live. Because I'm not finding anything. OK... OK.. I'm really... I'm just stuck...
 36 Yeah, I'm stuck. Either quit or ...I'm just looking to see what comes up under here, the
 37 subdivisions here (categories).I'm going back to Yahoo! Okay, I am about to go
 38 nuts, I just wanted you to know that so you can transcribe it. Isn't there a category for
 39 international? I guess that is somewhere else that I was. See, I need to get in the habit of
 40 bookmarking everything and taking it off when I am done with it. I think that would help
 41 because right now there is something that intrigued me but I didn't bookmark it, so I'm
 42 lost as to where it was. And that would have helped me a lot.

43

44 Top rated cities, oh actually, I would actually prefer the smaller cities. And that tells you
45 that you can buy this (book) so you can really compare and sit down for a long time. So
46 those are all guides that you can actually buy. That's what I want on the Web. And you
47 would think that has got to be something. Domestic and International, Adult and kids,
48 OK, we offer hands on cost-effective... OK, now see this is, OK, this is prepared for
49 foreigners coming to America to live. Which is sort of an interesting way to look at it.
50 Let's see if there is anything about... this is really for people who are not familiar with our
51 culture. If you are invited to a wedding... When you go "Dutch treat"... See, this is what I
52 mean, I start wandering, probably because at this point I am frustrated with what to do.
53 Now if I had \$75 I would just order this publication, but see, I am one who would still
54 rather read a book, and I tend to believe it more if it is in print. Even if it is from one of
55 these companies that are trying to sell me something. Since they publish in so many
56 different areas I'd be more likely to trust it. Because they aren't just selling in one area.
57 They just want to sell their books. I don't know why, because I mean a book and current
58 publications like that can be just as questionable material in a sense, but I guess that
59 since it has to go through some editors that I would tend to believe more than this (the
60 Web). I have to admit that when I am looking on the Web I have a hard time just because
61 anybody can put stuff up, I mean, when I was doing our Web page at first, I could have
62 put anything up and spun it whatever way and it would be up there. OK, it looks like
63 these are all services you can order. Guides. To make a smart relocation decision. "No
64 hype, advertising or sales pitch," I find that hard to believe. I wish there was something
65 where I could just put in certain areas and certain things I want in that field and it would
66 narrow it down for me. That is what I was hoping to find. This personal relocation
67 analysis, maybe that will give me something. This is a whole questionnaire. I wonder if
68 it is something that you have to mail in? See that would be great, but why isn't it available
69 on the Web? OK, so I'm feeling like a failure right now. Biiiiigg failure. We are not
70 moving, I'm staying here, cause I know what it is like here.

71

72 Oh, here's Redbook. Oh, now see this is neat, you can click your icon on this (image). I
73 like stuff like that, when I am looking I like the visual stuff, or like charts where you have
74 your buttons so you can go right to it. Working Mothers, that looks interesting. I don't
75 know if I should have done the search that way though, as a mom. I would like to see
76 what they have in general before I look at those cities. Maybe those weren't links, maybe
77 they were just a map. OK, and now I'm actually reading all of this (Redbook page). OK,
78 now I like this. See, now this is what I was looking for, I mean this is what would catch
79 my eye. It's like this sentence here... "These are places where there are a lot of working
80 mothers but not a hard driving culture in terms of hours and expectations." That would
81 be, and it says "The employers and the culture are supportive." That's what I need, family
82 time. That's why I tried to go through that parenting page at first, I was hoping that would
83 have something like this. OK, now this is just going to tell me how they got their ratings.
84 OK, this is for me, so I can look at specific things for me. 'Cause, I mean, then I have to
85 look at single-family housing. As a single mother that is a big thing. And Employers is
86 something I'd like to look at because I want to see if they offer daycare on-site. Madison
87 and Washington both interest me (out of the top 10 cities for working mothers). (She
88 clicked on Madison) OK, here is the narrative that I am looking for. Oh, it's a university

89 town, that is something I am looking for. And they have 8 daycares with the university
90 itself which is sort of nice. Wow, job sharing. Public schools are supposed to be good.
91 Enrichment, improvement, that's right, I forgot about the ski team they have. They have
92 a pretty good one. And they've got the bike trails and outdoor lakes like I like. OK, how
93 do I go back to the map? Let's try Seattle now. And Colorado.

94

95 Some more big city comments. I have to admit, just from those few word choices that it's
96 knocked it out. I don't want to live there. The housing prices keep going up with each
97 city I check. "Funky city," I like that. It's so funny how wording choices can influence
98 you. I guess that's why I am so cynical of anything that I read on other pages, knowing
99 that somebody is doing it. Isn't there a university in Boulder? I guess since they didn't
100 mention a university here,... but I think there is one. Now I'm just going to look at South
101 Dakota because it is in the general area. This is Redbook, I'm going to write down this
102 URL just for me. OK, now see the prices are better. Highest percentage of working
103 mothers, now that's interesting, in the country. Not a liberal city, OK. I wonder if that
104 means that it would be OK for single mothers? See I mean that is something else I would
105 like to know. That's what is hard when you are looking for a place in another culture or
106 country. You really don't know the culture until you are there. OK, from these I would
107 have to pick Madison, WI as my top from these choices. And I am looking now, just to
108 sort of verify. What I want to do is look under Madison and see if they have their own
109 site, to go further. So I am going to go back and, wait, I'm going to bookmark this one.
110 This is sort of not fair, because I've always wanted to go to the University of Wisconsin.
111 What's funny is that I came up with that from that listing.

Appendix 2. Sample Protocol from Study 2

Participant: Female, 50s, second grade teacher for 20 years

R=Researcher

- 1 *R: Well. Suppose your principal, Mrs. Boatman, said to you to look at the NCTM Standards*
2 *because it has good information for you on teaching second grade at Upland School. Is there a*
3 *topic or something about school math that you might be interested in looking for? <pause> Some*
4 *topic you want to teach? Or to see what kinds of things second graders are supposed to know?*
5 P: Let's do what second graders are supposed to know, I guess.
6 *R: Well, here you are! You are at the opening page for the NCTM electronic version of the*
7 *Standards for school math. What I want you to do is explore. See if you can find out how to*
8 *use this site, what's there, whether you can answer the questions you have. And I want you to talk*
9 *out loud. You know, if you click on a button, I want you to tell me why you clicked on that.*
10 P: OK. Tell you why I'm here. It's a good green color. It's a good place to start. (Clicked on
11 'Principles and Standards Documents' tab; then clicked on 'Table of Contents' on the right menu) I
12 don't know much about what I am looking at, Table of Contents. I guess I'm going to (clicked on a
13 link 'Chapter 3: Standards for grades pre-K-2)
14 *R: Why did you do that?*
15 P: It says pre-K to 2. And since I teach second grade...(scrolled down to see info)
16 *R: What are you looking for?*
17 P: I thought they have something specifically for second grade/pre-school and kindergarten. I'm
18 not sure that's what I want. (Scrolled up and down for info) I'm sure what I'm looking for. I was
19 looking for something specifically what second graders need to know. And it seems to be before
20 even going to school. And (pauses, reading and scrolling for info). Suppose the other thing is
21 environment to how to set up your classroom for this. Sometimes I think people they don't get into
22 classroom, knowing enough what to do in classroom. (saw the box 'Reader Reaction') I guess they
23 want me to read. Well. It's not what I want. (clicked Back button to go back to the Pre-K-12
24 introduction page)
25 *R: Why did you do that?*
26 P: Take it back to start where I was. Go back one page. Just to see if I can find some place to go.
27 (Clicked 'pre-K-2') I was there (scrolled down, scrolled fast. Saw nothing. Clicked Back button to
28 'Standards: Overview (Grades Pre-K-12): Introduction) I was there (chuckled, clicked the right
29 menu on 'Problem solving')
30 *R: Why did you go there?*
31 P: Well, it's something that we don't do very well in second grade. None of us, the three teachers
32 <at my school> did very well on that. So actually (pause...reading info. Scroll down)
33 *R: What are you looking for?*
34 P: Well, they just talk about why you should be good problem-solvers.
35 *R: Is that helpful?*
36 P: No. I know why you should be good problem-solvers. You have to solve problems every day.
37 Doing math is just applying problem-solving techniques to other areas in life. And I think good
38 problem solvers are children that will have a tendency to go and look into things and not to be told

39 they have to do it. (Scrolled down info) Good problem-solvers also can tell you what they did.
 40 Verbally or to write it down even.
 41 *R: Is any of this helpful? Just try to see what's being helpful here. Anything. And why you are*
 42 *looking at what you are looking at. Whether it's being helpful.*
 43 P: Well. They are trying to convince me that being a good problem-solver is the right thing to do.
 44 *R: What would you like to be there?*
 45 P: Umm?
 46 *R: What would you rather they would be doing?*
 47 P: Well, are they going to tell you, I mean, like lesson plans or umm, how to teach problem solving
 48 to the kids? I mean these are Standards. But knowing that these are standards does not help you
 49 with, if you don't know how to go about teaching problem solving and if all of your teaching is just a
 50 mess.
 51 *R: Where would you get things like that?*
 52 P: I haven't got a clue. (clicked 'Search' tab)
 53 *R: You've gone to the Search.*
 54 P: (typed: 'problem-solving-teach')
 55 *R: What do you think will happen?*
 56 P: It probably will tell me that's too broad a topic. (The screen showed 'nothing found')
 57 *R: What happened?*
 58 P: Told me that I didn't put in the right word.
 59 *R: Was it helpful?*
 60 P: No. (laughed)
 61 *R: Not helpful?*
 62 P: No, it's not helpful. (clicked Back button to go back to the Search page again). <Mutters under her
 63 breath>
 64 *R: Getting frustrated? It's OK.*
 65 P: That's why I don't do this; use the Web, because I don't know how to narrow things down.
 66 (Typed 'problem solve') Maybe 'method' would work better. (much more info is found) Geeze. See
 67 all this stuff? Well, maybe I didn't do it right. I don't want the Standards. (Scrolled down. Scrolled up.
 68 Sighed. Clicked Back button to go back to the Search page. Typed in 'method') See what
 69 'method' does. (A list of Standards, etc. came up. Sighed. Scrolled down.) Well. (clicked Back to
 70 Search page again) I didn't do it. (chuckled). I didn't get a clue. (Typed in 'second grade') Probably
 71 give me Standards again.
 72 *R: So you did second grade?*
 73 P: Yeah. Just doing second grade standards. (Scrolled down the results). I thought you told me that I
 74 was going to be able to find, I mean, topics of interest.
 75 *R: Well, I'm trying to see how you search. Whether it's obvious how to find things.*
 76 P: Oh, I don't think so. (Sighed. Clicked Back to the Search page. Typed in 'curriculum') Try
 77 'curriculum'. Or, that will come up even worse. (Some results came up. Scrolled down) I don't
 78 understand how (Paused, clicked one result link to 'Standards: Overview (grades pre-K-12)
 79 problem solving.' Scrolled down and up. Pointed at 'Home'. Not sure whether to click or
 80 not) Or, it's not going to make me back to (clicked on the 'Home' yellow tab) Alright.
 81 (clicked 'User's Guide')
 82 *R: Why did you go to that place?*

83 P: Oh. I failed to read the directions. (Sighed. Clicked 'Start here' on the right menu. The Web just
84 gave the existing page. Wondering what to click on the right menu under 'User's guide.'
85 (Clicked the 'Site Structure' on the right menu under 'User's guide.' Scrolled up and down.)
86 *R: Finding anything interesting?*
87 P: (Clicked on "Home" folder on the right menu under 'User's guide.' Scrolled down and up.
88 (Wondering what to click on the right menu. Then, clicked on 'PSSM' folder.) I'm just reading this.
89 (Clicked 'Search' folder) Sort of go through it. Just to see what it says. (Clicked 'Supplement' on the
90 left margin under 'Home.')

91 *R: Is that what you expected to see?*
92 P: I didn't know what Supplement meant. Boy. I don't understand. (pause)
93 I don't see any place for me to find out exactly what second graders should know, how to get there.
94 Nor do I see any place to go to find out a method for teaching something. So far, I see standards or
95 principles. For second grade, I don't know. I mean, I guess I expected to see something that says
96 'for second grade, children should know' and that's all. Listed. Because when we were doing the
97 science and we had the standards, they were listed like under 'for the first grade, this is what children
98 should know, second grade, ya da ya da. And they had several different standards. And I don't
99 know where I am. I don't know. (scrolled down) These are just examples of lessons. But I don't
100 know. (Scrolled up)

101 <Snip>
102 P: I don't think things are easy to find. (pause) OK. How do you do thought provoking
103 environment? Umm. What kinds of questions, examples? What kinds of questions you can ask all
104 during the day that would promote problem solving? You can't. You don't just do problem solving in
105 math. You also do problem solving in every part of your lives. So, some kids have disagreements.
106 Well. Problem solving. You don't go in to tell them, the kids, all the time, how to solve it. Just
107 yourself and the other kid, you solve it. Well. If kids learn to think that through, that also helps them
108 think things through, things in the math. So, what are other questions you can ask during the day that
109 help the children apply maybe some of the strategies that they are learning in math to other
110 problems in their lives? When you're in the classroom, you can't just narrowly, there's not enough
111 time for you to say we are only going to do math from this time to this time. Or, we're doing
112 English this time and this time. Can't do that. You got to integrate more and (pause) knowing how
113 to ask questions that would go across curriculum and be applied to all the subjects would be great.
114 Will be helpful. Extremely.

115 <Snip>
116 *R: So, when you are looking for information that may help you teach, where do you look?*
117 P: Where do I look? First, I look at the teacher's edition. My textbook, my teacher's edition that
118 goes with the textbook. I look at the supplementary things that they give along with, you know, the
119 textbook. And I think most places now offer a Web site. But I don't go there. Probably don't go
120 there for this very reason. It's very frustrating, number one. Number two; I don't have a lot of time.
121 So if I go some place, I want to be able to get my information quickly. I don't have time to browse
122 and look and sort things out. Umm. If I want to know where the standards were and the principles
123 of math are all here. And giving me general information about what they mean for a certain grade.
124 But this Website is not giving me specific things for use in my classroom to teach the kids that
125 would connect to each other. They're giving me ideas for lessons, yes. But connect them together so
126 that I make sure that I cover things and didn't jump over great big concepts, no. I'm not finding

127 that.

128 *R: So if you were designing it?*

129 P: From a teacher's point of view? I would give more concrete lessons.

130 *R: OK. How about the organization of things? How it is presented on the Website itself. You got lost in*
131 *certain times, how come?*

132 P: Because I think I was, I got lost because I was looking specifically for something, umm, in the
133 way of a lesson or more specific examples. And I couldn't find that. So I was frustrated on that.

134 And just didn't know where to go. Obviously, this site doesn't have what I would be looking for.

135 <Snip>

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