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ABSTRACT

Anchored instruction and anchored assessment are described and illustrated through a mathematics problem from the Jasper problem solving series developed at Vanderbilt University in Nashville (Tennessee). Anchored instruction is instruction situated in a context complex enough to provide meaning and reasons for why information is useful. Problems anchored in a complex context require anchored assessment, assessment that is a seamless, to the extent possible, part of the instruction process. A prototype assessment approach, the Jasper Planning Assistant (JPA), is described. Transfer from a single mathematical problem solving activity to reading comprehension of passages with analogous content, and the absence of transfer across content domains demonstrated in a study of 121 middle school students, is described. It is speculated that cross-domain transfer will require anchored instruction that provides a generator set of situations across which students could detect invariants that specify when higher order thinking skills would be useful. Assessment techniques for anchored instruction and situated learning must adapt to accommodate the non-linear topological dynamics that are seen when complex realistic problem solving is described as a perception-action cycle. Eight figures illustrate the discussion. Three appendixes provide sample Jasper verbal protocol and analysis, and two samples of JPA output. Thirty-eight references are included. (SLD)

Anchored Instruction and Anchored Assessment: An Ecological Approach to Measuring Situated Learning

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Anchored Instruction and Anchored Assessment: An Ecological Approach to Measuring Situated Learning

The benefits of teaching in a complex realistic context have been suggested by many sources from Dewey (1938) to the recent discussions of situated learning and situated cognition. Context provides meaning, enriches perception, and affords development of complex problem solving and higher level thinking skills. If this is so, then we must develop means to creatively assess the effects of anchored instruction, benefits to mathematical thinking and beyond, across subject domains and across transfer situations. This paper discusses the Jasper Planning Assistant as an assessment of higher level mathematical thinking. In addition, we describe transfer from a single mathematical problem solving activity to reading comprehension of passages with analogous content, and the absence of transfer across content domains. We speculate that cross-domain transfer will require anchored instruction that provides a "generator set" of situations across which students can detect invariants that specify when higher order thinking skills, such as planning, would be useful. We conclude that assessment techniques for situated learning and anchored instruction must adapt to accommodate the nonlinear topological dynamics that are inherent when complex realistic problem solving is described as a perception-action cycle.

The benefits of teaching in realistic contexts have been touted for a long time (e.g., Dewey, 1938; Whitehead, 1929). For example it has been suggested that situated and experiential learning in everyday settings both provide meaning to our current activities (e.g., cognitive apprenticeships, Collins, Brown, & Newman, 1989) and impel or give meaning to what happens next (Lave, 1988); that is, the environment influences both perception and action. At a basic level, nearly all agree that situations are a part of learning, whether in the form of episodic memories, merely as part of the backdrop for learning, or more fundamentally integrated with learning as described by the ecological psychology of James Gibson (1979). The ideas of "situated learning" take the view that situations are inevitably an integral part of what is learned: <u>all</u> learning is situated and, therefore, learning should be done in authentic (see Note 1) settings (see for example, Brown, Collins, & Duguid, 1989). Recently, an even stronger assertion about situations has been put forth: that not only learning, but all thinking is, in fact, situated. This is the psychology of situated cognition (Clancey & Roschelle, in press; Greeno, 1989). These acknowledgments for the importance of situations in learning and thinking compel researchers to consider more closely the advantages and limitations of teaching through situations (anchored instruction) and to develop means to assess "situated learning" (anchored assessment).

We view complex situated problem solving from the perspective of ecological psychology. From this perspective we acknowledge the primacy of the interaction between the skills and abilities brought to the situation by the problem solver (effectivities) and the affordances for action provided by the problem environment or problem space -- a symmetry of acausal interactions (Shaw, Turvey & Mace, 1982). This relationship is captured in the perceiving-acting cycle that temporally unfolds through the problem-solving process. It would not be meaningful to characterize the problem solving of an individual apart from the context in which that problem solving occurs. A situated cognitive analysis of thinking must describe both the abilities that each person brings to the table as well as all the relevant attributes (affordances) of the environment including dimensions of the problem and problem space that afford certain actions. In contrast to Skinner's (1987) impoverished conception of environmental stimuli, an ecological approach acknowledges the richness and complexity of the information available in the environment and its co-determinant role in thinking.

The "situatedness" of knowledge is consistent with much of what psychology has learned in several areas. Psycholinguists have strongly acknowledged the importance of context, citing simple examples such as "indexicals" (I, you, here, there) that only have specific meaning in a particular situation (Bruner, 1986; Miller & Gildea, 1987). Sociologists have also acknowledged that context (particularly culture) arises from and gives meaning to social interactions (Coulter, 1989; Saxe, 1991). Using an ecological perspective, we have found it useful to apply this analysis to mathematical and scientific thinking, specifically problem solving. That is, when viewed from this perspective, knowledge, thinking and problem solving are not properties of individuals, but rather, they "live" in the interaction between the capabilities of problem solvers and attributes of the problem (specifically the problem and solution spaces). When perception is emphasized over memory, it is the information picked up from the environment that is perceived and acted upon, and which must become part of assessment, not simply the actions or results of problem solving.

Kugler, Shaw, Vicente, and Kinsella-Shaw (1991) described goal-directed activity, such as problem solving, as an interaction of attractor sets, specifically the attractor sets supplied by a complex realistic context (affordances) and the attractor processes (effectivities) by which we achieve the goal-states set up by our problem solving intentions. Their analysis suggests that it is the information available from a situation that guides and constrains problem solving: "The behavior of inanimate systems is lawfully determined by a force field, whereas, the behavior of animate systems is lawfully specified by an information field (p. 408)." In their analysis of self-organization and intentional systems (such as people), they give mathematic substance to Gibson's (1979) principle of "organism-environment mutuality." Applying these ideas to anchored instruction suggests that problem solving is an interaction between the problem solving skills of the individual problem solver and the activities and manipulations that a particular problem affords. In their terms the interaction between agent and environment (problem solver and problem) is inherently nonlinear:

> Fields that have hidden degrees of freedom (internal fields) are said to be *compactified.* The relationship between local and global fields is promoted here to express the relationship between an environment and the organisms acting in that environment. The compacting of an external field by internal field properties expresses exactly the contributory role perceptual/cognitive variables play, along with physical variables, in codetermining the observed behavior of the organism. This, we propose, is what it means to say that an organism, as a perceptually attuned intentional system, is informationally as well as forcefully coupled to its environment. (p. 422)

In taking an ecological perspective of complex problem solving, we also acknowledge.that problem solving is individual in an essential way. Each person's interaction with the environment, specifically a problem space, is unique. The environment is constantly changing (You never step in the same river twice-- Socrates) and the problem solver's ability to detect relevant information in the environment and act on it is also continually changing (perceptual learning). As a result, the interaction that <u>is</u> problem solving evolves-- subproblems are discovered, new plans and goals are constructed, and in the terms of intentional dynamics, equilibrium points are created and annihilated in the problem solution state space.

Using these fundamental concepts from ecological psychology, we first describe the nature of anchored instruction, citing the Jasper problem, "Journey to Cedar Creek" as our example (see Note 2). Next we describe the objectives of anchored assessment. We describe our prototype, the Jasper Planning Assistant (JPA) for assessing mathematical thinking in the Jasper environment, and our initial attempts to use traditional paper and pencil measures to assess cross-domain transfer from the Jasper context. Finally, we describe our views of progress toward assessment of cross-situational transfer, as would occur for students completing a "generator set" of situated problems, for example, all episodes of the Jasper Series.

The nature of anchored instruction

Anchored Instruction is a term coined by the Cognition and Technology Group at Vanderbilt (1990) to describe a special type of situation for learning. Consider that it is possible to situate learning in two ways. The first is exemplified by many law school courses on tort law, where a separate real-world case is used to explain each new dimension of law. In this tradition, it is possible to encounter several cases in a single course lecture. Such situations can be considered microcontexts for each specific topic to be learned. In contrast, it is also possible to select "macrocontexts" that are sufficiently rich and complex to be meaningfully viewed from several perspectives. The Cognition and Technology Group at Vanderbilt (1990) describes the use of a feature-length film, "Young Sherlock Holmes," to anchor instruction for a semester-long investigation of Victorian era history, scientific concepts (weather, geography and inventions), and aspects of literature (story grammars, vocabulary, and readings related to the context). The use of a single film for an entire semester might, at first blush, invoke images of students bored to tears when viewing the film for the tenth or thirtieth time. But learning new perspectives of material that students thought they initially understood completely, proved to be challenging and motivating to students. It was the changes in understanding (perceptual learning) that proved motivating, not simply the presentation of the situation.

Perhaps the strongest and most obvious advantage of anchored instruction is the use of complex realistic contexts to provide meaning and reasons for <u>why</u> information is useful. Brown et al. (1989) reiterated the metaphor that knowledge is a tool. While one can possess a tool (e.g., a band saw), it cannot be said that one has knowledge of the tool unless it can be used to build something. In this case, it is the building that provides the meaning and motivation for learning about the band saw. At any point in a lesson on learning the band saw, a student could meaningfully respond to a question of why they are working so hard, by appealing to the importance of building the building-- the meaning and reasons for <u>why</u> information is useful. It is unlikely that an equally meaningful explanation would be given by a student learning logarithms in a traditional Algebra classroom.

Van Hanaghan, Barron, Young, Williams, Vye, and Bransford (1992) showed that students who solve mathematics problems "anchored" in a complex context (episode 1 of the Jasper series entitled, "Journey to Cedar Creek," described later) acquired problem solving skills, such as problem formulation and relevant information detection, to a greater degree than did students who solved isolated, decontextualized word problems. These data provide evidence that anchored instruction affords acquisition of all the knowledge and skills typically taught in the abstract by traditional mathematics texts and techniques, including for example, the ability to solve traditional mathematics word problems. But in addition to specific mathematics algorithms, using an anchor situation for learning also provides teachers an opportunity to direct students' attention to general approaches to problem solving (higher order thinking skills) and invariant information available in the problem space (specifying affordances for particular problem solving strategies). That is, an anchor situation affords teaching to transfer across the various academic domains that relate to the situation.

The Cognition and Technology Group at Vanderbilt's (1990) work with "Young Sherlock Holmes" supported the idea that contexts can provide meaning for learning. While providing an opportunity to learn traditional school topics such as history and science, the movie situation also provided the meaning for why one needed to know such things and how they applied to understanding a realistic situation. Working in a complex realistic context was also motivating, but not due solely to the context itself. Experiencing new insights and gaining new perspectives on what was thought to be understood and mastered was surprising and motivating for students.

Experiencing new perspectives and acquiring new understandings of what one already knows can be considered perceptual learning. Drawing on concepts from ecological psychology, the experiences of the students working in the Jasper and "Young Sherlock Holmes" contexts can be viewed as "tuning their attention" to "see" the context from the various perspectives of a scientist, then a mathematician, then an historian. Each new insight changes and informs students' perceptions of different affordances of the context, which can potentially enhance subsequent problem solving in this and similar contexts-- as described by Kugler et al., changing the nature of the attractors in the external and internal fields (see Greeno, Smith, & Moore, in press, for a discussion of transfer of situated learning).

Traditional classroom activities simply do not afford students an opportunity to tune their attention in the same way as when students are engaged with complex realistic problem-solving environments. In order to attend to the meaningful, stable elements of an environment (what Gibson calls the "invariants"), the students must be active and generative with the environment (Slamecka & Graf, 1978), as well as interact with the environment across a significant period of time. The fractionated 40 minute periods of traditional classrooms (40 minutes of math, then 40 minutes of science, etc.) and isolated simplified activities (with reduced cognitive load, Chandler & Sweller, 1991) do not provide the necessary experiences for students to detect the invariants among the complexity of any one situation or the more general information related to problem solving that is invariant across multiple situations. Anchored instruction is more than simply advocating knowledge in depth rather than knowledge in breadth (di Sessa, 1988). The suggestion here is that anchored instruction in a complex realistic environment affords the tuning of attention to ecologically valid events (perceptual learning) in a way not possible in traditional classrooms, and in a more naturalistic way consistent with everyday experiences and everyday cognition.

Anchored mathematical problem solving in the Jasper context provides more than experience with the specific solution to a single math problem (Jasper's trip up river to buy a boat). The realistic context also provides students an opportunity to acquire information about a range of river-related concepts that are given meaning by the dialog, pictures, and activities occurring in the Jasper story. From a ecological psychology perspective, students are given an opportunity to "tune their attention" to various affordances of these objects. The students' resulting enhanced perceptual system (perceptual learning) is then available to assist other activities (perception-action interactions with the environment), such as reading comprehension, by providing meaningful representations either from memory (mental models) or more directly through perception. If this is so, then when assessing the claims for anchored instruction, we must detect not only successful ongoing problem solving (the goal-solution path selected) but also transfer of perceptual learning across the multiple domain perspectives possible on a single anchor situation (e.g., mathematics, science, history, and reading) which is indicative of perceptual learning.

The nature of anchored assessment

As the techniques of anchored instruction are adopted and instruction becomes more collaborative, situated, and distributed in its sources of information, traditional means of assessment (relying mostly on multiple choice tests) will be quickly proven inadequate. Multiple choice items that assess the static factual knowledge of students must be replaced by cognitive tasks and assessments (including the use of the multiple choice format) that can focus on the information and perception-action processes that constitute situated realistic problem solving.

Assessment must acknowledge that learning, knowledge, and thinking are "situated," and as such are different for each individual in each unique situation. The complexity of acknowledging individual differences means that individual standards must be accepted. Some means must be adopted to capture the richness of the perception-action interaction of each student with the problem environment. Jenkins (1977) warned us of this complexity:

> For the contextualist no analysis is 'the complete analysis'... There is no one analysis, no single and unified account of anything. What makes an analysis good or bad for us is its appropriateness for our research and science and its utility in our pursuit of understanding and application (p. 416, quoted in Carello & Turvey, 1991)

Assessment can no longer be viewed as an add-on to an instructional design or simply separate stages in a linear process of pretest, instruction, posttest. While paper and pencil measures can contribute to an understanding of situated learning, assessment must be an integrated, ongoing, and seamless part of the learning environment. In short, instruction and measurement must be constructed and implemented as one (see Snow & Mandinach, 1991). This is anchored assessment.

Assessment must not only be integrated with instruction, but also focus on the problem solving process along with problem solutions (Case, 1985). In the context of Jasper problem solving, Kulikowich and Young (1991) have cited the need for assessments that externalize the critical processes of problem solving that are only implicitly available from verbal protocols. We described the paradox of verbal protocols: just when the most critical cognitive activities are occurring, the least amount of verbal reporting is done. This may be interpreted as a workload problem (doing and reporting at the same time) or may reflect the automaticity of the problem solving skills involved (proceduralized, conditionalized perception-action links that must play out from beginning to end). The use of anchored assessment that is integrated with anchored instruction can provide more information about the critical perceptual and cognitive processes of problem solving, more seamlessly, without steering attention completely away from the problem itself.

There are two main audiences for anchored assessments of situated learning: teachers and problem solvers themselves. In anchored instruction, the role of the teacher changes and in many ways becomes more difficult than teaching through traditional didactic lecture. The role of an adult (knowledgeable about the situation) is to guide student's attention to features of the situation that are invariant and therefore meaningful across a class of situations, features that novices would typically overlook. In this case, assessment information enhances the teacher's ability to detect the information in the environment to which students are attending. Students themselves can also take advantage of this new source of information, as they work in cooperative groups and attempt to socially construct knowledge through discourse. Data gathered about the information field and problem solving process of each group member could facilitate discussion and the "perception-action cycle of the group." Seamless individual (or collaborative group) assessment could then provide important feedback to both teacher and student, and when supplemented with information about common misconceptions, errors, and malrules in particular situations, could perhaps be instantiated as a partner or "knowledge navigator" in the process of problem solving.

Computer technology can make seamless assessment a reality. Computer-based instruction can have assessment measures embedded within it. Often these include time on a particular component of the task, time to completion, graphic representations of solution paths or concept maps, as well as traditional solution steps and answers. However, when learning changes from direct instruction to situated learning, the assessment of successful and less successful learners (or experts and novices within a domain) must change from an emphasis on right/wrong responses toward an emphasis on the information that each student perceives and uses in the situation(s). The affordances that students perceive can be detected by the types of information to which they attend (Jasper video scenes replayed), the paths taken toward solution (solution spaces), the types of analogies and transfer that occur, error patterns (misconceptions or malrules), and the nature of transfer across domains and across situations. In short, to measure the technology-rich situated learning afforded by anchored instruction, anchored assessment is needed. Anchored assessment should be a seamless (as seamless as possible) continuous part of the activity (a learning/ assessment situation), enabled by technology, and complemented by innovative measurement and psychometric techniques.

The Jasper Videodisc as Anchored Instruction

Research on situated learning suggested a need to develop in students a knowledge of real situations that encompassed more than merely engaging in mathematical calculations or isolating scientific facts (Cognition and Technology Group at Vanderbilt, 1990). The complex realistic situation provided by the Jasper videodisc afforded us an opportunity to immerse students in a problem-solving situation for a week of regular mathematics classes, and to look for transfer from this single anchored activity. The student's role in solving Jasper was to be an active problem solver. Successful problem solving in this context required problem-solving intelligence, knowledge of how to access and retrieve relevant data, when and how to rely on alternative data sources, how to operationalize needed information as mathematical computations, and how to manage and intelligently take advantage of information throughout the problem-solving environment; in short, what Pea (1988a; 1988b) has called "distributed" intelligence.

Briefly, anchored instruction using Jasper's "Journey to Cedar Creek" videodisc involved viewing a15-minute story in which the major character, Jasper Woodbury, encounters a problem; specifically, he buys a boat with a small temporary fuel tank and broken running lights and wonders if he should start for home on the boat. All of the data required to obtain a quantitative solution to the problem has been embedded in the story. Working in groups of 3 or 4, students are challenged to list all of the things they must consider to decide whether Jasper should leave for home on the boat (e.g., time of sunset, fuel needed, distances, speed, etc.). Then, they are asked to generate and document their solutions (all solutions must be "proven"). Throughout this time, the videodisc is made available for students to retrieve relevant facts and information on request, accessing the disc themselves using a Hypercard® interface. The solution space for this Jasper problem is characterized by 17 or more separate steps, including calculations, comparisons, and decisions, leading to a simple Yes or No decision as to whether Jasper should leave for home in his new boat. Students work for 5 days during their regular mathematic classes. On the last day each group presents their solution.

Anchored Assessment of Jasper problem solving with the JPA

In traditional classrooms, the typical assessment of mathematical problem solving involves relatively simple (relative to the 17-step Jasper problem) one- or two-step word problems presented as text. Even in the typical Jasper classroom, more standard measures of the effects of anchored instruction with Jasper are generally employed-- Likert-style items of attitudes toward mathematics, computation problems for dividing decimals or subtracting time, and transfer word problems presented as text. All these methods are administered after the Jasper problem has been solved, tend to emphasize results over process, and tend not to challenge students at the level of complexity that is present in the actual Jasper problem. But the concepts of anchored assessment suggest that Jasper problem solving can be the assessment, as well as the vehicle for instruction. With the aid of technology, assessment measures that focus on the process of Jasper problem solving can be married to anchored instruction activity, and result in a more detailed description of the process.

The Jasper Planning Assistant (JPA) is a HyperCard®-based automated data system for the Jasper problem solving series. The system currently exists in prototype form. For the Jasper problem solver, the system appears as basically an automated Fact sheet for information recalled or retrieved from the videodisc. However, there are several other features available to assist the problem solver, including 2 "pages" to help generate and review plans (a Planning Page and a Question Generating menu), an automated worksheet with a built-in calculator, and a Video Search Controller that controls the videodisc (see Figure 1).

Before problem solving begins, JPA requests general student identification, and asks several self-report Likert-scale questions pertaining to computer experience, mathematics ability, and interest in topics related and unrelated to the Jasper story. Jasper problem solving begins with a student viewing the 15-minute story, beginning to end. Near the end of the story the problem arises and all the information needed to make a quantitative decision about that problem has been embedded in the story. As the story ends, the problem is posed to the students for them to adopt and solve.

At this point, the JPA has the capability to ask the student 19 questions related to various aspects of the story; including Social (What did Jasper and Sal do for lunch?) Math (How many feet long were the barges?) Science (What was the name of the device used to measure the depth of the water?) Story (What did Sal cook with while out on the river?) and Basic Facts (Identify each character by their picture).

At the outset, the "Planning Page", shown in Figure 2. is presented and students are asked to develop six important questions that define the subgoals necessary to answer Jasper's problem. Students then are taken to the "Facts Page" as a worksheet for their continued problem solving. Students are encouraged to create additional planning questions as needed as they work through the problem. The requirement that students clearly state questions before giving solutions is a form of "scaffolding" to encourage the development of planning skills (e.g., Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, in press; Soloway, Guzdial, Brade, Hohmann, Tabak, Weingrad, & Blumenfeld, 1991). Planning skills are acknowledged as important higher order skills associated with identifying what one does not know about the information in a complex context (Graesser & Hemphill, 1991). For our purposes, there is an added advantage to requiring students to clearly externalize the questions they develop as they work toward a solution; namely, they provide a trace of student planning. This is important assessment information that is typically <u>not</u> available from verbal protocols alone, but is acquired seamlessly by the JPA.

The "Question Generating (Chinese Menu) Page" ,shown in Figure 3, is available to reduce typing requirements and assist students in formulating their planning questions. It provides three columns of phrases that can be combined to form all the required questions, as well as many irrelevant questions. For example, the left column contains phrases such as "Will Jasper" and "How far is it"; the middle column contains phrases such as "have enough", "from Cedar Creek", and "from Willie's"; and the right column contains phrases such as "time", "fuel", "to Jasper's home", and "to Willie's." These phrases could be combined to form the important planning questions "How far is it from Cedar Creek to Willie's?" and "Will Jasper have enough fuel?" They could also be used to form irrelevant questions such as "How far is it from Willie's to Larry's?" Thus, while this "Chinese menu" approach helps students to generate planning questions, it does not restrict those questions to such an extent as to make those questions obvious. Student-generated questions are automatically transferred to the Planning Page.

The "Fact Sheet Page" shown in Figure 4 is a repository for all facts that students recall from the video, retrieve by reviewing scenes or generate by calculating quantitative answers to their planning questions. For example, after initially viewing the video, a student may remember that Jasper started his trip at mile marker 132.6 on the river. This fact would be entered on the Fact Sheet. The student might then create the important planning question, "How far is it from Cedar Creek to Jasper's home?" The student then would re-view a scene to find that Cedar Creek is at mile marker 156.6 on the river. The student would be prompted to enter this fact on the Fact Sheet also. Then using the calculator, the appropriate subtraction problem might be done and the result stored with the appropriate planning question. At this time the JPA would automatically add the statement and answer, How far is it from Cedar Creek to Jasper's home: 24, to the Fact Sheet.

The "Calculator/Answer Sheet Page" shown in Figure 5 is an automated worksheet that students are required to use for all calculations. This system enables students to generate equations representing their selection of mathematical operations in service to solving the Jasper problem and to transfer their numerical answers onto the Planning Page and associate them with specific planning questions. This page automatically records the equations generated by the student to serve as data for the assessment model. Thus, it permits analysis of the ability to mathematically define Jasper's world, and other important higher level skills; specifically, the ability to take mathematical equations and map them onto real life physical events (Shoenfeld, 1988).

The "Video Search Controller Page" contains a graphic map, representing Jasper's trip, in which "clicking" on various locations on the map replays the story scenes that occurred at that location in the story. Using this interactive map, students can re-view scenes from the story with the associated embedded data they contain. Figure 6 illustrates this page with the cursor highlighting the location "Larry's". The events that occurred at that location are made available to the student in a window in the lower right corner. Clicking on any of these titles would cause the videodisc to replay that segment of the story. Each time a scene is replayed by the student, frame numbers and their verbal labels (e.g., "Arriving Larry's") are recorded in a "dribble field," on a hidden "Data Page". This information enables our assessment to consider what information students seek, verify, and retrieve from the story, their sequence and latency. We imagine that expert problem solvers will show a pattern of retrieving relevant information in the most efficient sequence, while novice problem solvers may view irrelevant information and re-view scenes in less than optimal order (e.g., a fact about money, then location, then fuel, then another money item, etc.). This information plus the data contained on the fact sheet externalizes, to some extent, the "information field" perceived by the problem solver: those features of the environment on which they have focused their problem-solving attention.

Figure 7 shows the Data Page that contains the dribble file and other information collected by the JPA. Included in the dribble file are each planning question, entered fact, calculation, and video frame revisited, preserving the sequence in which it occurred. In addition, the time spent on each page of the JPA, results on the 19-question story test, self ratings of efficacy and interest in related domains, and the student's confidence in their final solution are recorded. These data are a unique contribution to the assessment model since they reflect the student's ability to recall sequences of information from the Jasper story, to access pertinent facts as they are needed in problem solving, to plan and to calculate-- in short, higher level thinking skills of successful problem solving. Therefore, in addition to the capability of the JPA to monitor planning and mathematical operationalizing, the JPA can tell us about how students are able to structure knowledge so that it can be readily accessed to solve problems. Knowledge access has been a key factor in discriminating expert from novice performance (Chi, Feltovich & Glaser, 1980; Glaser, 1984; Larkin, McDermott, Simon, & Simon, 1981).

Comparing the data obtained from the Jasper Planning Assistant with data from a typical verbal protocol of Jasper problem solving highlights the psychometric advantages of the JPA: the JPA requires students to externalize more of the critical components of problem solving, their planning, operationalizing (selecting the appropriate mathematical operation), the facts they are using, and where they retrieved these facts from the story. Most students state the products of their planning in a verbal protocol, rather than the planning itself. As illustrated in Appendix A, this requires processes then be assumed or inferred when the verbal protocol is analyzed. For example, subjects often state facts that they have found ("The tank was half full") or the results of mental computation ("It's a 12 gallon tank") as show in Appendix A. Output from the JPA makes the information and calculations more explicit (see Appendix B).

Output from the JPA also affords us several other analysis capabilities. Similar to dividing verbal protocols into "speech acts" or the solution space into "idea units," we have been able to identify "problem-solving acts" in JPA output (illustrated in Appendix C). As shown at the end of Appendix C, total time (in seconds) spent using each of the five JPA components is available. In addition, information that is included in our paper and pencil assessment, such as self-efficacy measure, measures of interest, and confidence in one's final solution, is also collected and summarized by JPA. We see the externalized data available through the JPA as providing a significant measurement advantage over verbal protocols alone (Kulikowich & Young, 1991).

Assessing cross-domain transfer within the Jasper context

If situations (anchors) are providing meaning for instruction and opportunities for perceptual learning, then there is no reason to believe that the resulting understanding should be constrained strictly to the domain of the specific problem that is solved (in the case of Jasper, distance- rate- time and mathematics, as measured by the JPA). Rather, if it is a deeper meaning and new perceptions of the context that are facilitating learning, then once acquired, those new perceptual abilities should be available to facilitate understanding across traditional subject domains-- facilitating an integrated curriculum through anchored instruction (Cognition and Technology Group at Vanderbilt, 1990).,

In a recent experiment, we believed that learning in a realistic problem-solving environment like the Jasper series would provide the meaning and "why's" for problem solving, as well as provide students an opportunity to enhance their perceptions more generally for river/boating contexts. Logically, that meaning and new perceptual ability should be available to facilitate comprehension on tasks beyond the Jasper mathematics problem, as long as those environments contained the same or similar elements (invariants) to be perceived (i.e., analogous content). To investigate this contention, we undertook a study that asked, "Does mathematical problem solving in the Jasper river/boat context facilitate later reading comprehension of a narrative passage about rivers and boats?" We further tested this idea by including an additional narrative passage in an unrelated context (horses), with the understanding that the meaningfulness provided by the Jasper video might transfer from mathematics to reading comprehension with analogous content, but it should not transfer to an unrelated context that does not provide similar affordances. Transfer to a new context, the horse passage, could, however, be explained if more general (higher order) thinking skills, shared between the mathematical problem-solving task and the reading comprehension task, were being enhanced by the Jasper activity.

Results from 121 middle school Jasper problem solvers generally indicated a treatment effect on the River and not the Horse passage, using 2 measures of comprehension, a multiple choice vocabulary test and a sentence completion recall test (and a general vocabulary pretest as covariate). Factor analysis patterns of the individual recall items showed a consistent pattern with the salience of items to the Jasper problem and solution space (see Goldman, Vye, Williams, Rewey, Pellegrino, & the Cognition and Technology Group at Vanderbilt, 1991). Elements that were related to goals higher in the Jasper solution space (e.g., running lights associated with the time subgoal), constituted a single factor on which experimental students performed much better than Controls (see Figure 8). We suggest this as one innovative way to use paper and pencil items to assess situated learning. Our findings were mitigated by strong school and gender interactions that are explained, in part, by situated cognition (e.g., suburban school students looking for invariance in the Horse passage that simply did not exist). These results are discussed in detail by Young and Kulikowich (in preparation).

In short, we believe that it may be somewhat surprising that viewing a 17-minute video that merely mentioned running lights in the context of a river trip, followed by 3-5 class days of mathematical problem solving, showed benefits to reading comprehension on a passage that also mentioned, for example, running lights. But we contend that is was not the initial story viewing alone that contributed to this finding. Rather, it was the immersion of students in the river context, through their extended mathematical problem solving, that enhanced their ability to comprehend passages also related to the river context. The benefits of anchoring instruction in one academic domain (mathematics), using a complex realistic context, are thus demonstrated to transfer to another academic domain (reading) that was not the target of any instruction during the intervention.

Conclusion

Anchored instruction represents a new way to immerse students in realistic complex problem-solving situations. From an ecological psychology perspective, each student working in an anchored instruction environment is given an opportunity to apply their problem-solving skills (described as a perception-action loop) and to tune their perceptual systems by detecting invariance of scientific and mathematical concepts (such as the distance-rate-time relationship) and other information that specifies the usefulness of specific higher level problem solving strategies (such as planning in a complex solution space and detecting relevant from irrelevant information). There are distinct advantages to considering problem solving from an ecological perspective. For example, the role of a higher level thinking skill such as planning is no longer a single step in a stage model of problem solving; rather, is becomes a continuous dynamic interaction when problem solving is a perception-action loop.

Given these advantages over traditional instruction, we suggest the need for situated views of assessment. Such "anchored assessment" should be characterized by attention to individual differences (agent-environment interactions within a complex situation) and seamless dynamic assessment integrated with instruction. Computer technology, used to implement anchored instruction, can also serve the purposes of anchored assessment, as exemplified by the prototype JPA. Paper and pencil measures (even those using traditional multiple choice formats), analyzed for consistency with descriptions of the problem space, can also serve to inform situated learning assessment models.

As a closing note, we would like to briefly discuss the ultimate goal for situated learning: cross-situational transfer. Data collected and analyzed for this paper have so far only concerned a single episode of Jasper problem solving. Greeno, Smith and Moore (in press) point out that multiple situations are really needed for students to acquire the general, heuristic knowledge that is essential to mathematical and scientific thinking. The Cognition and Technology Group at Vanderbilt (1990) also acknowledged the need to provide an intelligently selected and sequenced set of situations (e.g., the Jasper Series) that provides students an opportunity to detect the components of their solutions that are invariant across an entire class of problems. But little research has been done on the development and design of the proper "generator set" of situations that will enable students to learn algebra or political theory or any of the traditional classroom subject. Yet, it is only after students have experienced the generator set of problems (limited in number, but designed to optimize perceptual learning) that we would expect to observe cross-situational transfer.

Not only is assessing a single individual in a single situation complex, but this complexity is compounded when considering assessing changes in perception across a generator set of anchor situations. Kugler et al. (1991) discussed the complexity of intentional behavior using a concept from nonlinear discontinuous mathematics, a *germ*. Citing Weir (1985), they describe goal-paths as actually:

> ... a bundle of virtual paths that may agree (are defined by the same mapping and show the same analytical continuation) up to a point of discontinuity, called a *bifurcation point*; after which they might bifurcate into a collection of separate paths, with each representing a different possible realization of the goal. This bundle of virtually separable goal-directed paths is called a germ, and is not a function since, at the bifurcation point, it is *one-to-many* (Auslander & MacKenzie, 1977). (p. 410-411)

Applying the Kugler et al. model to problem solving, problem solvers would perceive the germ directly from the problem situation.

> ...Actors perceive the tranformability of current action states, despite thwarts, into future goal-accessible routes precisely because they *perceive* the germ of the generalized action potential specific to a given goal. The germ... contains all of the analytical and nonanalytical mappings from past states to goal-states. (p. 411)

This analysis suggests that from an ecological psychology perspective, the fundamental nature of problem solving is nonlinear. Problem solving proceeds as a perception-action loop, in which "germs" are perceived, problem solving actions are taken, and new constraints arise. Alternative assessment models will be needed to capture the complex perception-action interactions characterized by changing attractor topologies that define the problem space for each individual (information fields) and their interaction with it. In these models, each individual problem solver perceives a *germ* that specifies the potential goal-paths to solution of the problem. These paths, and therefore their assessment, are fundamentally nonlinear. Across a generator set of situations, each problem solver is given an opportunity to tune their perceptions to the invariant structure of the problem solving interaction. As we continue to develop the tools, such as the JPA, needed to observe a problem solver's progress toward solution (along with the information perceived and acted upon), psychometric theory may need to adapt and expand to complement the nonlinear dynamics of the individual-environment interaction.

Note

1. Ten attributes of "realistic" or "authentic" settings are given by Young & McNeese (in press). They describe authentic contexts as those that make contact with our intuitions, common sense, and everyday knowledge; contexts in which the goal is clear, meaningful, and accepted; and contexts that afford the kinds of problem solving that requires cooperative groups and access/integration of information from distributed sources.

2. The "Jasper Series", developed by the Cognition and Technology Group at Vanderbilt, is marketed by Optical Data Corporation. The series is being used for ongoing research efforts at the University of Connecticut and elsewhere with permission and cooperation from the Learning Technology Center, Peabody College, Vanderbilt University, John Bransford and Susan Goldman, co-directors, Box 45 Peabody, Nashville, TN, 37203.

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Figure 1. Organization of the JPA.

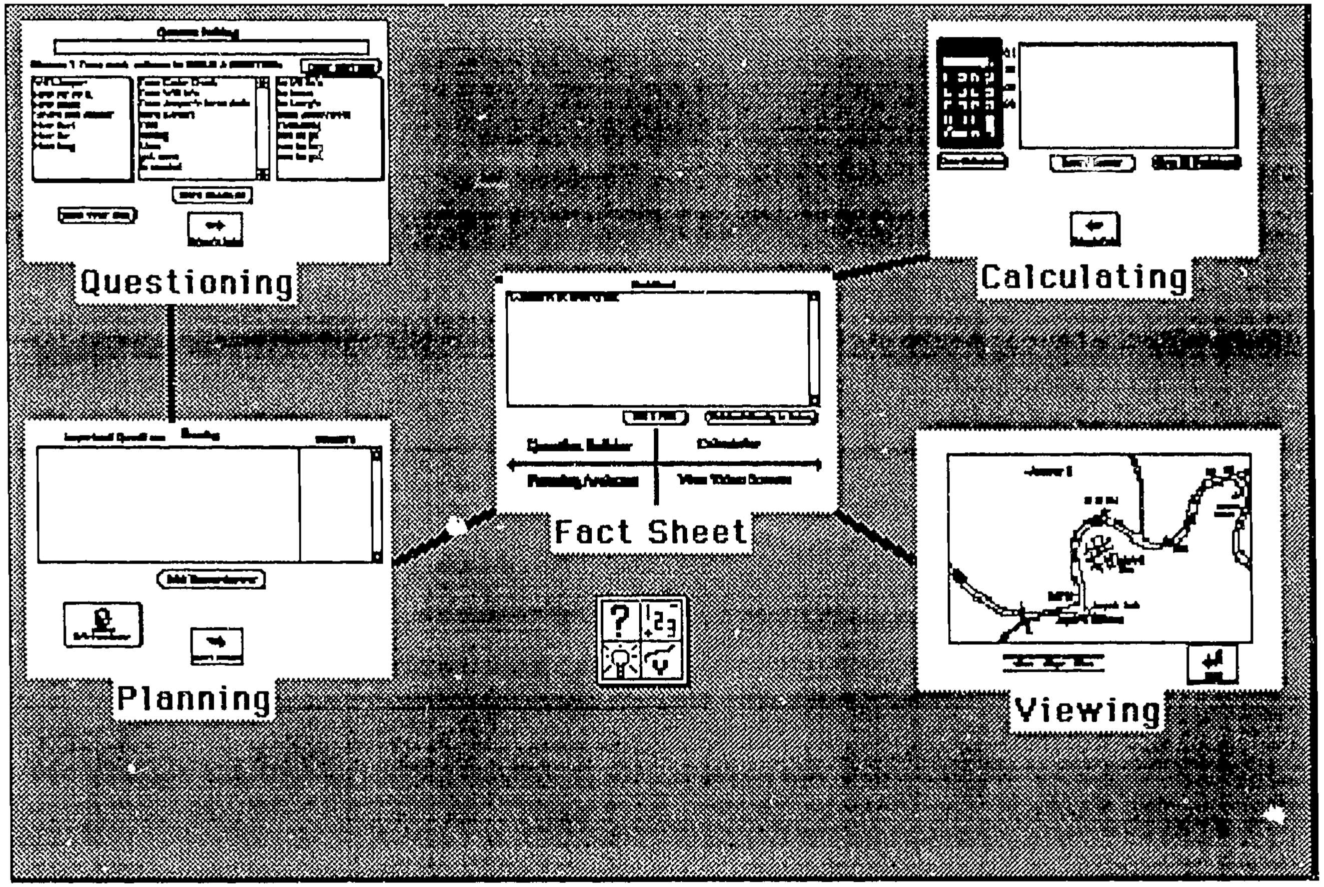


Figure 2. Planning Page.

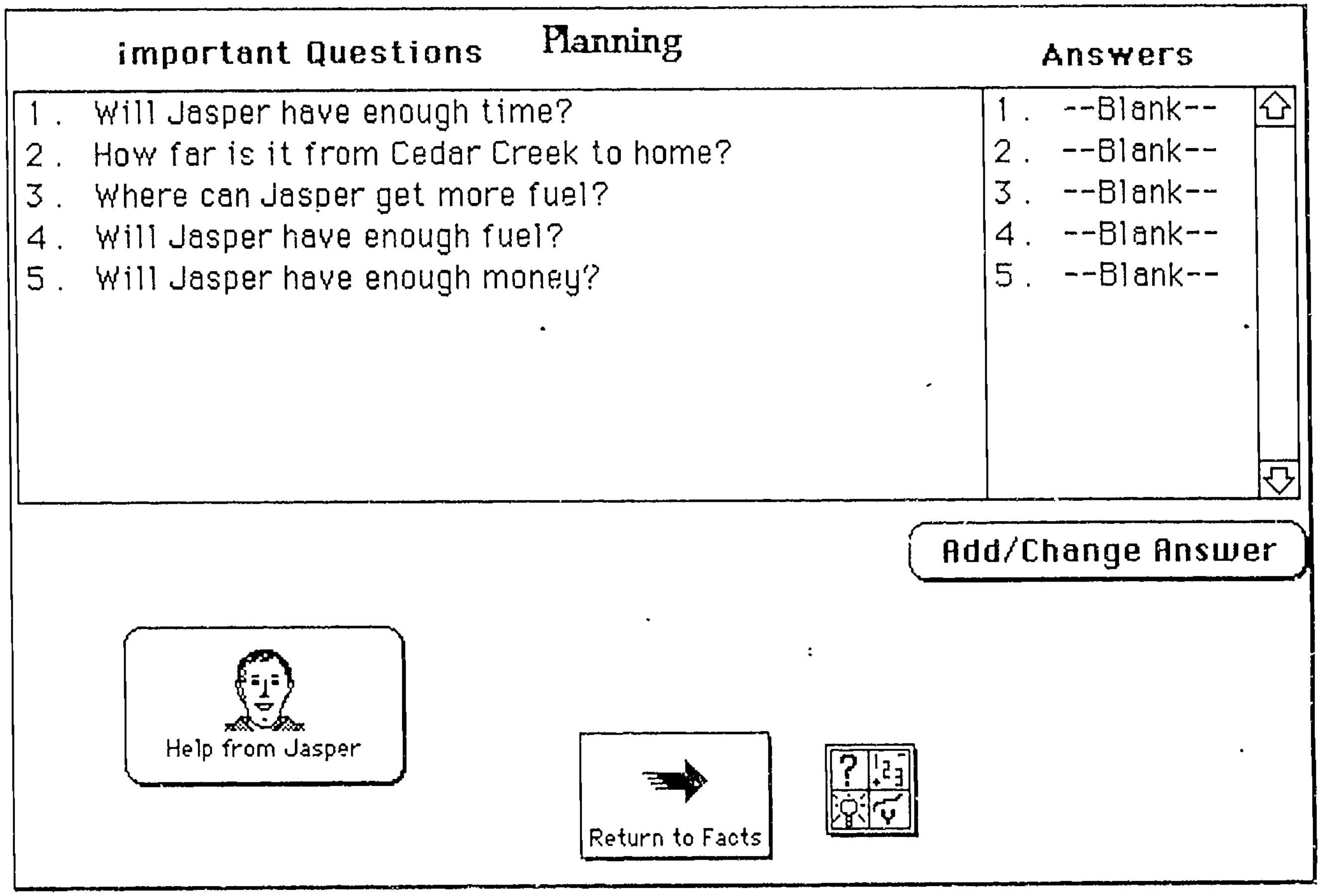


Figure 3. Question Generating (Chinese Menu) Page

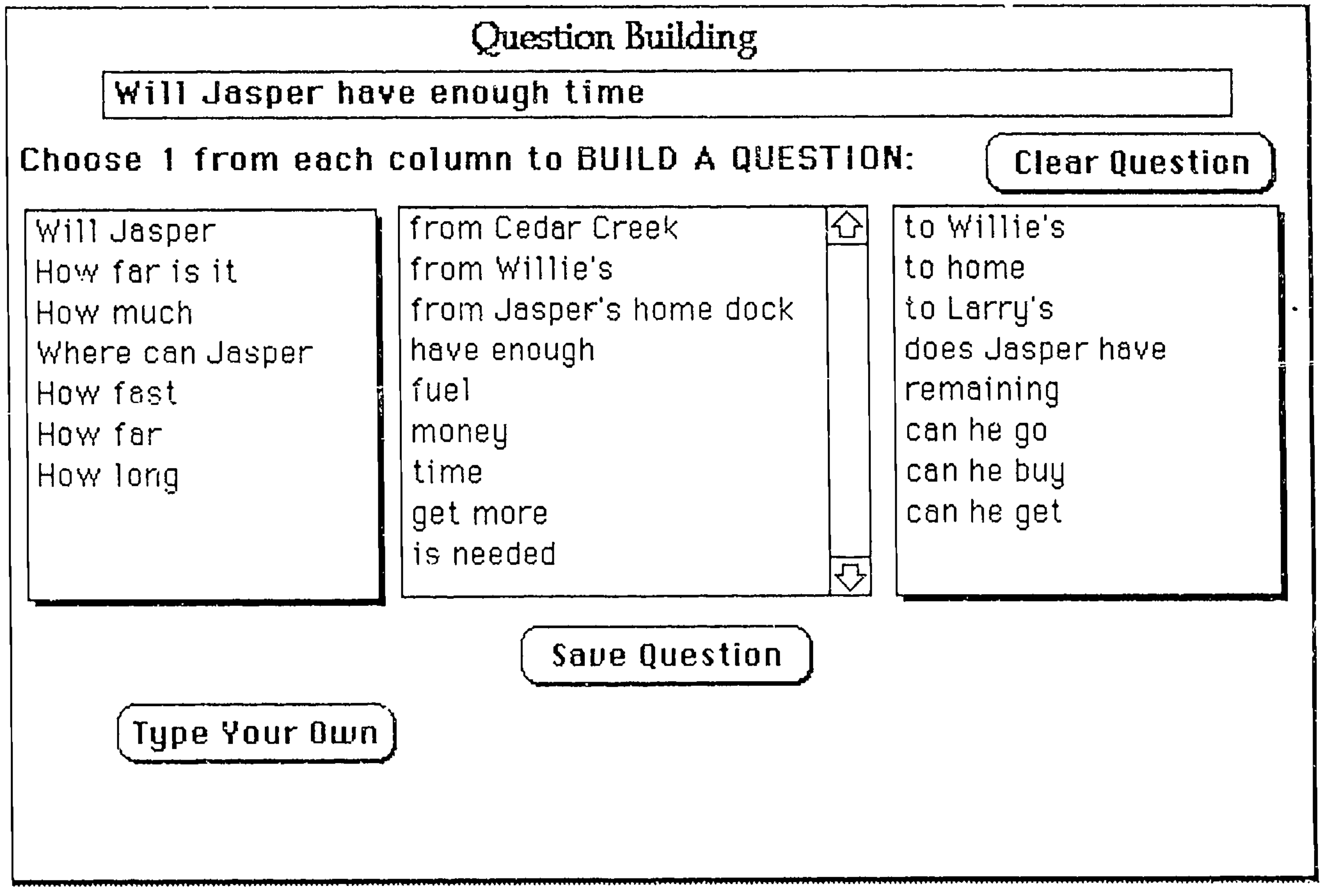


Figure 4. Fact Sheet Page.

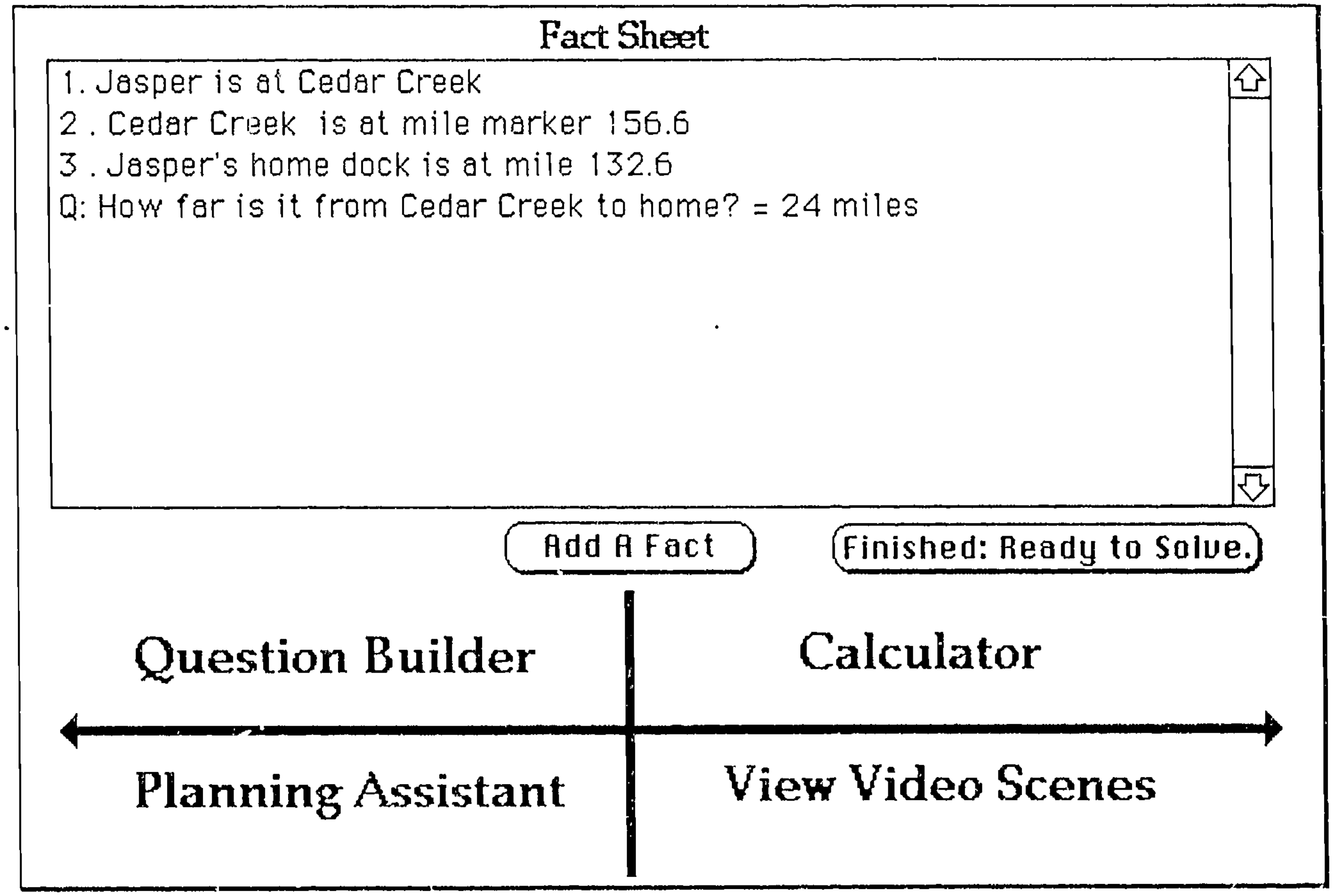


Figure 5. Calculator Page.

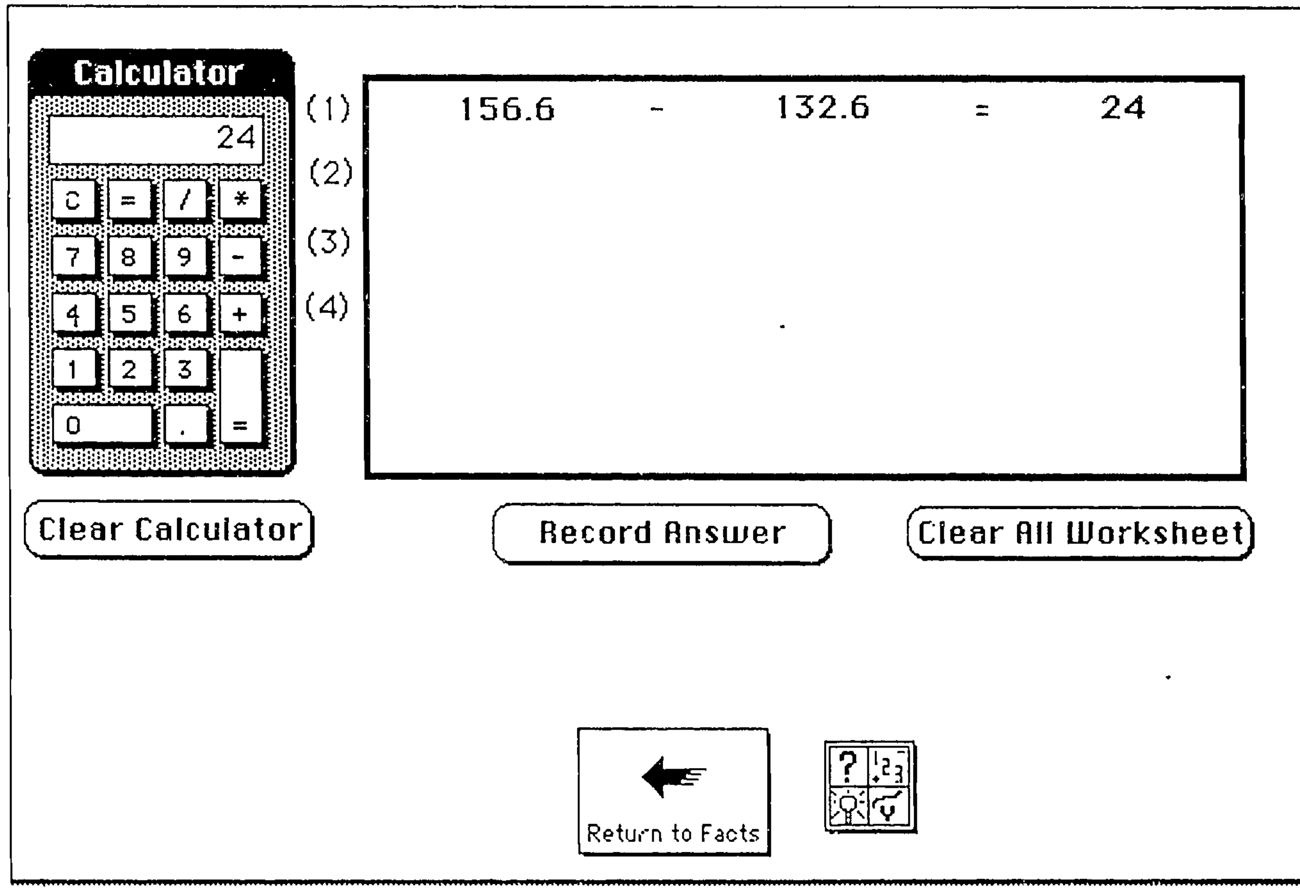


Figure 6. Video Search Controller Page

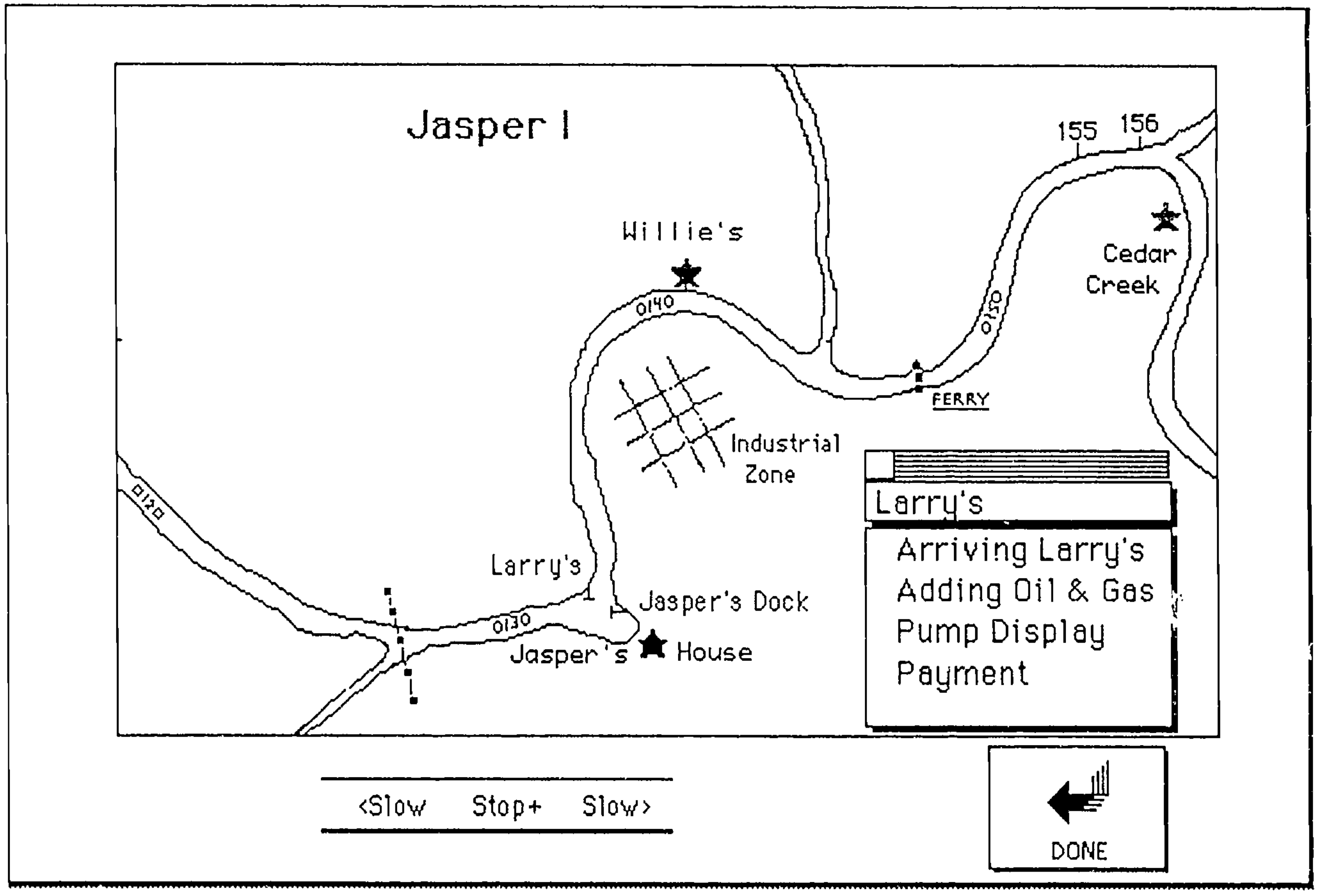
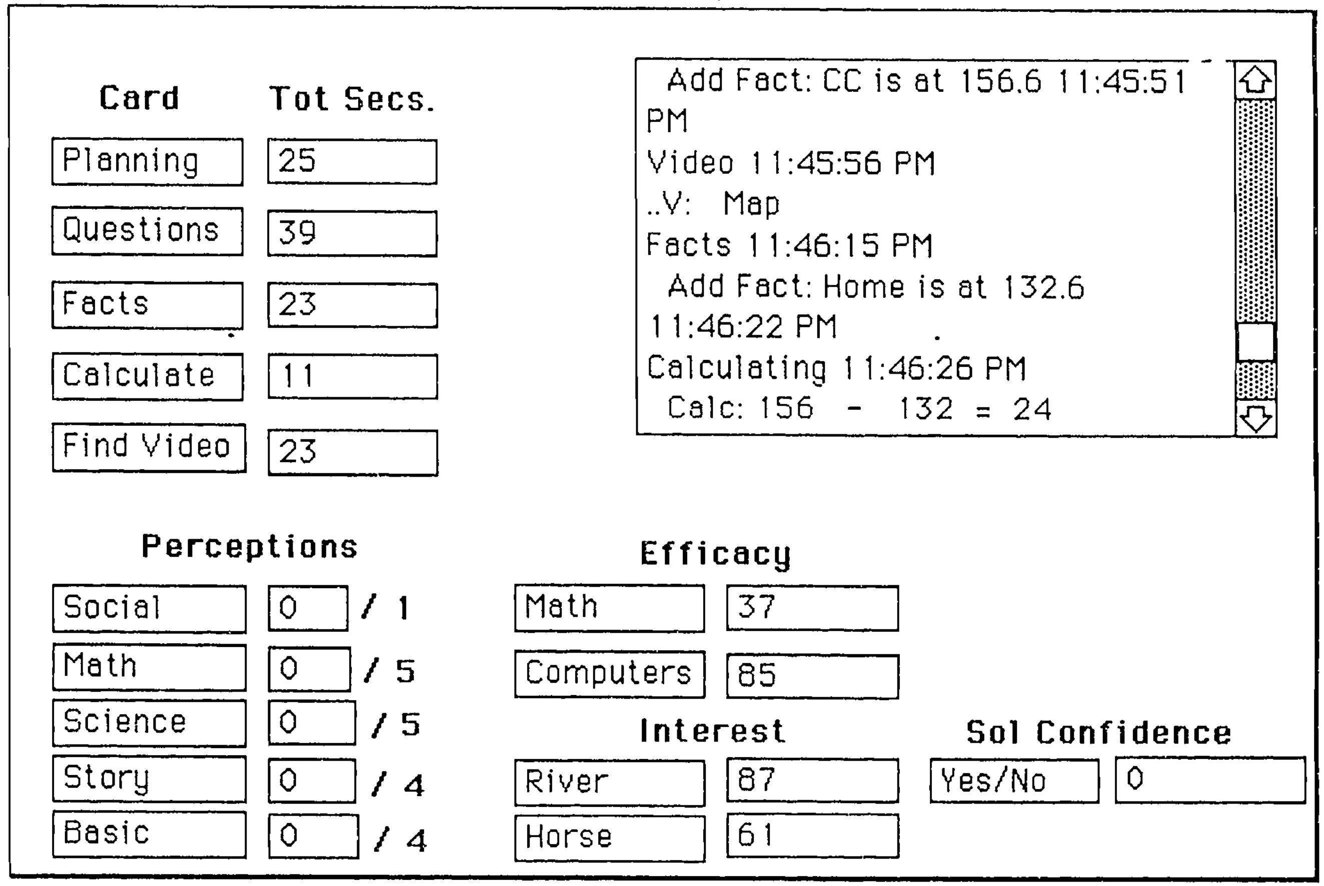


Figure 7. Data Page.



Appendix A. Sample Jasper Verbal Protocol and Analysis

Here is a "typical" Jasper verbal protocol. The subject initially only considers FUEL as the deciding factor and incorrectly concludes that Jasper should not leave for home. However, when prompted, the subject has all the necessary skills to compute the information needed to reach the complete and correct solution. This protocol might be characterized as Lo Planning, high info finding, high operationalizing, and high motivation/attitude (roughly). Yet, the planning and many other important "idea units" must be inferred from what is stated...

Subject: C B Date 12-8-89

The tank was half full and it took 6 gallons, so it's a 12 gallon tank. It's a 12 gallon tank. It burns 5 gallons an hour. It took 7.5 minutes to go one mile. And let's see. Looking for the distance here [You looking at the map?] Yeh. {PAUSE}. Alright. I'm going to subtract 156.6 from 132.6, that's 24 miles. So it's 24 miles, it'd take him...multiply 7.5 minutes...it'd be 5 gallons an hour, and that's just 3 hours, and that's 15 gallons. Jasper should not do it. He shouldn't do it, he'd run out of gas. [Alright]

Now, revisiting this first section of unprompted problem solving...

The tank was half full and it took 6 gallons,
We must assume the subject has planned: Does Jasper have enough fuel.
so it's a 12 gallon tank. It's a 12 gallon tank.
We assume the calculation 6 * 2 = 12.
It burns 5 gallons an hour.
We assume the S found the relevant fact from Sal's statement.
It took 7.5 minutes to go one mile.
Again assume correct information finding.
And let's see. Looking for the distance here [You looking at the map?] Yeh. {PAUSE}.
Here the E prompts for information finding source (map)
Alright. I'm going to subtract 156.6 from 132.6, that's 24 miles.
Assume the correct information retrieved from map, and
assume S stated problem wrong (since answer was given as 24, not -24 miles)
So it's 24 miles, it'd take him...multiply 7.5 minutes...it'd be 5 gallons an hour, and that's just 3 hours, and that's 15 gallons.
This is a complex series of calculations, but one can break it out and assume the following...

1. multiply 7.5 time 24 = 180 minutes.
2. 180 minutes / 60 = 3 hours.
3. info found: 5 gal/ hour
4. 5 gal/hr * 3 hours = 15 gallons needed.

Jasper should not do it. He shouldn't do it, he'd run out of gas. [Alright]
While this conclusion is justified & quantified, planning for the rest of the problem did not occur. The rest of the transcript demonstrates that had the S considered the other factors, he could have reached the correct solution.

Protocol continued...

Appendix B. Sample JPA Output.

Student: J.T.
Starting: 11/6/91
Time in: 1:54:32 PM

CARD FUNCTION	TIME	
HOME-START	1:54:32 PM	
Names	1:54:35 PM	
Which data	1:55:11 PM	
Base Control	1:55:24 PM	
Intro Card	1:56:09 PM	
Planning	1:56:21 PM	
Facts	1:57:35 PM	
Add Fact Cedar Cr. is at 132.6 mile marker		1:58 PM
Add Fact J. needs to get to his dock at 132.6 MM		1:59 PM
Video		
	2:05:18 PM	
Arriving Cedar Creek	2:05:59 PM	
Stopped at 10147	2:06:02 PM	
Arriving Cedar Creek	2:06:47 PM	
Stopped at 09968	2:06:51 PM	
Facts	2:07:00 PM	
Add Fact Cedar creek is really at 156.6		2:07 PM

... Output continues ...

Planning	2:26:20 PM	
Questioning	2:26:31 PM	
How much fuel?	2:26 PM	
Add Question How much fuel?	2:27 PM	
Planning	2:27:02 PM	
Facts	2:27:06 PM	
Calcu	2:27:41 PM	
6 * 2 = 12	2:28 PM	
Add Calc Result 12	2:29 PM	
Planning	2:29:12 PM	
Planning	2:29:12 PM	
Facts	2:29:21 PM	
Questioning	2:30:40 PM	
Planning	2:30:50 PM	
Add Answer 12 gals.	2:31:09 PM	

... Output Continues ...

Planning	2:47:40 PM	
Base Control	2:47:46 PM	
Your Answer	2:47:49 PM	
Solution = YES	2:47 PM	
Title Screen	2:47:56 PM	

Appendix C. Sample JPA Output.

JPA Output		Problem-Solving Act
Student: A. A. Starting 8/19/92 Time in: 11:38:42 AM		
Tutorial		
Instructions		
Facts	12:06:07 PM	Estimating Mile Markers
Video	12:06:20 PM	
Facts	12:07:18 PM	Entering Facts
Add Fact: from 129 to 157 12:07:46 PM		
Calculating	12:07:51 PM	Calculating (distance)
Calc: 157 - 129 = 28		
Questioning	12:08:36 PM	
Planning	12:08:36 PM	Entering Answer
Facts	12:08:47 PM	
ANSWER: How far from Cedar Creek to home? = 28 miles		
Planning	12:09:06 PM	
Facts	12:09:16 PM	
Video	12:09:18 PM	Info Finding (speed, 7.5)
..V: 1 Mile Test		
Facts 12:10:18 PM		
Calculating	12:10:32 PM	
Calc: 28 * 7.5 = 210		Calculating (time)
Calc: 210 / 60 = 3.5		
Planning	12:11:57 PM	
Questioning	12:12:58 PM	Entering Answer
Planning	12:12:58 PM	
Q: How far is it from Cedar Creek to home?	12:13:21 PM	
ANSWER: How far is it from Cedar Creek to home? = 3.5 minutes		
Planning	12:13:28 PM	Correcting Units
Change Answer 6 to 3.5 hours		

Facts	12:14:21 PM	
Video	12:14:23 PM	
..V: Map		Info finding (T sunset)
..V: Boat Leaving		
Facts	12:16:32 PM	
Add Fact: sunset is at 7:52	12:16:59 PM	
Video	12:17:02 PM	Info finding (T current)
..V: Jasper Thinks		
Facts	12:18:10 PM	
Add Fact: he is ready to leave at 2:35	12:18:29 PM	
Calculating	12:18:34 PM	
Facts	12:19:42 PM	Calculating (T available)
Calculating	12:20:22 PM	
Calc: 5.2 = 5.2		

... Output Continues ...

Summary Data:
Total Time Planning: 570, Total Time Questioning: 357, Total Time Facts: 807,
Total Time Calculating: 491, Total Time Viewing: 1043
Rated Math Efficacy: 77, Rated Computer Efficacy: 78,
Rated River Interest: 52, Rated Horse Interest: 26,
Rated Confidence in Solution: 84

Time out: 1:00:36 PM

Figure 8. Jasper Story Factor Hierarchy