DOCUMENT RESUME

ED 373 735 IR 016 745

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TITLE Embedding Metacognitive Cues into Hypermedia Systems To Promote Far Transfer Problem Solving.

PUB DATE 94

NOTE 21p.; In: Proceedings of Selected Research and Development Presentations at the 1994 National Convention of the Association for Educational Communications and Technology Sponsored by the Research and Theory Division (16th, Nashville, TN, February 16-20, 1994); see IR 016 784.

PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150) -- Tests/Evaluation Instruments (160)

EDRS PRICE MF01/PC01 Plus Postage.

DESCRIPTORS *Computer Assisted Instruction; *Cues; Higher Education; Hypermedia; Learning Processes; *Metacognition; Pretests Posttests; *Problem Solving; Qualitative Research; Thinking Skills; *Transfer of Training

ABSTRACT

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Title:

Embedding Metacognitive Cues Into Hypermedia Systems To Promote Far Transfer Problem Solving

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ABSTRACT

A pretest-posttest control group design with random assignment, together with qualitative data collection and analysis, was used to investigate whether metacognitive, cognitive and affective-awareness cues embedded in a hypermedia program could facilitate college students' near and far transfer of problem solving in biology learning. It was assumed that when subjects are asked to explain reasons for their own actions during the problem solving, they must engage in self-reflective intermediate processes comparable to metacognitive processes of monitoring, evaluating, and regulating ongoing problem solving. Four treatment groups were used: one received metacognitive cues; one received cognitive cues, one received affective-awareness cues, and the control group received no cues. Results showed that subjects in the metacognitive group performed better on far transfer tasks than all other groups. The qualitative analysis indicated that metacognitive-oriented questions encouraged students to "stop, think and reflect" on their problem solving processes which in turn helped students understand the process of how the problems were solved. The understanding of processes students went through to solve problems helped them transfer what they learned to novel situations.

Introduction

One of the primary goals of education is to enable individuals to develop skills which allow them to continue self-education throughout their lives. In the past 15 years, helping students develop self-regulated learning skills has been commonly known as helping students develop skills of learning how to learn. Self-regulated learning is defined as the extent to which the students are metacognitively, motivationally, and behaviorally active participants in their own learning processes (Zimmerman, 1986).

The heart of self-regulation is developing the awareness and capacity for effective planning, monitoring, reflecting, and modifying one's own learning processes (Corno & Mandinach, 1983; Brown, Bransford, Ferrara, & Campione, 1983). Corno and Mandinach (1983) further suggest that long-term exercising of self-regulated learning activities will help students at all levels learn how to learn and develop school aptitude and motivation. It is important to note that the definition of self-regulated learning encompasses metacognitive, cognitive, and affective processes. Flavell (1976) defines metacognition as the awareness and active monitoring of one's cognitive processes. In problem solving, the metacognitive processes monitor the selection and application of solution processes as well as ongoing feelings about self and task. A metacognitively aware learner is able to "apply, adapt and/or modify what they have learned to new tasks and across different situations" (Rowe, 1988, p. 228). It is the understanding and regulating of their own cognitive processes that enable students to tackle new tasks, solve new problems, and transfer learning across domains (Pintrich, Cross, Kozma, & McKeachie, 1986; Glaser, 1984; Rowe, 1988; Berardi-Colette, 1990; Dominowski, 1990).

Transfer is defined as the process in which students use previously learned knowledge and skills to successfully solve problems in new situations (Gagné & Berliner, 1988). It can be divided into two levels: near and far transfer. Near transfer refers to situations in which training situations and problem tasks are almost identical (Butterfield & Nelson, 1991; Salomon & Perkins, 1989). Far transfer occurs when knowledge and skills are successfully applied to a highly novel problem, and it requires creative use of knowledge and strategies learned (Clark, 1992).

A growing body of literature supports the notion that optimal academic performance is strongly tied to the degree of self-regulation the learner is capable of exercising (Zimmerman, 1990; Borkowski, et. al., 1990; Pintrich & DeGroot, 1990; Corno, 1986). As a result, considerable attention has been focused on the phenomenon of self-regulated learning. There has been much progress made in (1) identifying knowledge structures and processes that underlie self-regulated learning and (2) recognizing the importance of a motivational component in addition to metacognitive and cognitive components (McCombs & Marzano, 1990). The integrative nature of the concept may lead to increased theoretical complexity of the construct and a greater understanding of learning processes. However, to use the concept of self-regulation as a realistic guide for everyday classroom situations, there is a continued need for theoretical and empirical research which shows how each component of self-regulation impact learning and problem solving. Further research is also needed to learn more about the role affective-awareness plays in contributing a better problem solving performance. These needs provided the theoretical basis for this study.

Computer technology is thought to hold great potential for more effective teaching of self-regulated learning skills (Henderson, 1986). It has been suggested that technology-based instruction is likely to result in citizens who know how to learn and will continue to learn in the future if the program used emphasizes self-discovery of new ideas, helps learners gain feedback about their ideas, and encourages them to assess their own ideas (Linn, 1983). Hypermedia systems, a fairly recent advance in technology, provide more potential and advantages to learning over conventionally programmed CAI due to their greater degrees of flexibility and capacity for individualized instruction (Bourne, 1990). The term "hypermedia" is defined as an advanced technology that combines film, video, computer graphics, sound, music, and text in a unified information-delivery system centered upon the personal computer (Paske, 1990). It is a mixture of technologies controlled by hypertext. Hypertext is the term that is used to describe non-sequential writing, text that branches and allows choices to be made by the learners (Paske, 1990). In a hypermedia system, the information can be organized in a non-linear manner and a topic can be explored in multiple ways (Spiro & Jehng, 1990).

In addition to the theoretical problem posed earlier, two practical problems were also addressed in this study that involve the role of hypermedia in students' learning. They were: (a) how each component of self-regulated learning processes (metacognitive, cognitive and affective processes) influenced positive near and far transfer of problem solving skills; and (b) how hypermedia should be used to promote self-regulated learning which might lead to positive transfer.

Although previous research has shown that positive problem transfer is difficult to obtain (Thomas, 1974; Gick & Holyoak, 1980), studies requiring subjects to explain reasons for actions while solving problems have consistently shown positive transfer effects (Gagné and Smith, 1962; Berry & Broadbent, 1987; Berardi-Coletta, 1990; Stinessen, 1985). These studies typically required subjects to "state reasons" for their actions during the problem solving. Most of these studies dealt with college students in solving the types of problems involving puzzles. They all found successful near and far transfer effects. Most of their explanations for the positive effect on solution transfer have been limited to speculations that verbalization induced more planning and forced subjects to think (Gagné and Smith, 1962), and verbalization provided the metacognitive experience needed for successful transfer. However, it was not clear what was responsible for the positive transfer, verbalization or metacognitive processes.

Berardi-Coletta's (1990) study answered these questions. She concluded that it was not verbalization which produced the positive transfer effect. Rather, metacognitive processes enabled subjects to understand the process of how the problem was solved, which led to positive transfer (Berardi-Coletta, 1990). Giving reasons for one's own actions involved learners in metacognitive process (Berardi-Coletta, 1990). She also found in her study that negative self-evaluation distracted learners from focusing on the task, and thus produced negative effects on transfer performance. However, she did not explain how affective-awareness influences near and far transfer of problem solving. Further, it was not demonstrated in these studies if the use of self-explanation cues to induce metacognitive processes which were effective for puzzle problem transfer remain effective for content-rich problem transfer.

It is also important to investigate whether embedding question cues in hypermedia system to encourage learners to self-explain their own problem-solving processes is effective for content-rich problem transfer because technology is likely to become an increasingly common component of learning in both education in schools and business training. With the advent of technology, especially hypertext and hypermedia which provide high levels of flexibility and autonomy for learners to explore and construct their own learning, it should be possible to assist learners to acquire self-regulatory processes that are essential for effective transfer of learning.

In summary, the theoretical needs to explore how each individual component of self-regulated learning theory impacts learning and problem solving, together with the practical needs to investigate how hypermedia systems should be used to promote self-regulated learning and positive transfer of problem solving, provide the rationale for this study.

The purpose of this study was to investigate 1) whether metacognitive, cognitive, and affective-awareness processes provoked by self-explanation cues embedded in a hypermedia simulation system improves immediate near and far transfer problem solving in biology learning; 2) how subjects respond to metacognitive, cognitive, and affective cues; and 3) how metacognitive, cognitive and affective cues influence students' task design in the hypermedia system during the training.

It was hypothesized that there would be no differences among groups in near transfer. However, subjects who received metacognitive cues were expected to perform better than subjects who received cognitive or affective cues and students who received no cues in immediate far transfer problem solving. Subjects who received cognitive and affective cues were expected to perform equally well on immediate far transfer of biology problem solving. However, subjects in cognitive and affective groups were expected to perform better than subjects in control groups (no cues).

Methodology

Experimental Design

This study involved pretest-posttest control group design with random assignment, together with qualitative data collection and analysis. There were three treatment groups and one control group. The three treatment groups were: (1) a metacognitive group which responded to question cues from the computer program which asked subjects to plan ahead of time, monitor the process, evaluate the results and modify task design; (2) a cognitive group which responded to question cues that asked subjects to explain specific rules, goals, strategies which were related to the content of specific problems); and (3) an affective-awareness group which responded to question cues that asked subjects to explain their concurrent feelings, or to compare feelings at the beginning to those at the end. Subjects in the control group did not receive any cues. All of the groups received the same level of training, which differed only in the types of cues on which training focused. The locations of the cues were the same for all of the three treatment groups. The program was identical for all treatment groups except for the specific cues. Appendix 1 lists the content and locations of the cues for all three groups.

The independent variable was the type of cues: metacognitive cues, cognitive cues, affective-awareness cues and no cues. The dependent variables were near and far transfer of problem solving.

Subjects

Eighty-eight pre-service elementary education majors enrolled in an introductory course in biology at Purdue University volunteered to participate in this study. The total enrollment of the class was 205, with 195 females and 10 males. The distribution of the class was approximately one-third juniors, one-third sophomores, with the rest a mixture of freshman and seniors. The study was an extra credit project option provided by the instructor. Originally one hundred forty students signed up for the project. But only eighty-eight were included in the data analysis due to several technical difficulties, which included program bugs and system compatibility problems. Among eighty-eight subjects, eighty-four of them were females and four of them were males. All of them passed content tests so that content knowledge would not be a factor that influenced the performance. Only 5% of the subjects were familiar with Macintosh computers. However, experience with computers was not considered a concern to the project.

Materials

This research project was part of a laboratory experiment which had been found to be problematic for students enrolled in the class in the past. The content selected for the hypermedia-based training task was a series of experiments designed by the students to test the effects of light and moisture on isopod behavior. We will refer to these as the "student tasks", to avoid confusion between this experiment and the experiments which the students were designing. To solve these problems, subjects had to recognize the need to control variables and understand random behavior to verify their derived solutions, identify experiments which did not produce useful data, and repair them. It has been suggested by several researchers that the lack of metacognitive reasoning abilities might be the major factor inhibiting subjects from solving this type of problem successfully (Lawson, Blake, & Nordland, 1975; Lawson, 1979; Piaget, 1962; Lawson & Nordland, 1976).

Training tasks were built into a hypermedia simulation program running on Apple Macintosh™ personal computers that linked Authorware™ (Macromedia Inc) and HyperCard™(Claris, Inc.). There were six options in the program menu, and subjects were given the freedom to select their own content, pace and paths. The program was developed by the authors of this paper.

Another commercial program, Screen Recorder™(Farallon, Inc.), was also running at the same time when a randomly selected sample of subjects were using the simulation program. This program created a "record" of everything that happened on the screen, including the selected subjects' time on task, sequence of their selections, design of the tasks, learning paths, and frequency of selection of each option. The purpose of this program was to collect qualitative data on how the different cues influenced subjects' responses and design of the experiments.

The test of near transfer measures required subjects to work with a preset experimental design to test the effect of moisture on isopod behavior. The far transfer, however, asked subjects to design an experiment to determine which of three possible causes (peer influence, diet, or family environment) were responsible for an increase in hyperactivity in a hypothetical elementary school class. Both near and far transfer tests were developed by the instructor of the course. Refer to Appendix 2 for the copy of test.

Procedures

All of the students met for the lecture once per week for 50 minutes. There were also nine hands-on laboratory classes with about 25 students per classes. When registering for the lecture, subjects signed up for the lab classes based on their schedules for the semester. There was one instructor for the lecture and nine teaching assistants (TAs) for the lab divisions. Each hands-on lab division met for two 90 minutes sessions/week, and there were always two teaching assistants present.

The project was divided into three phases, pre-treatment (four weeks), treatment (two weeks) and post-treatment (one week). The pre-training was conducted because it has been suggested by Berry and Broadbent (1984) that concurrent verbalization or self-explanation may only have a significant effect when accompanied by pre-task training on how to respond to the questions.

During the first week of the pre-treatment phase, TAs were introduced to the project by the researchers. The purposes of the project, time required of TAs for help, and overall plan and scope of the project were all explained. They were also asked to go through the computer program as well. The researchers went to the lecture to explain the project to all of the students. The policy for extra credit was explained as well as the learning benefits students might obtain by participating in the project. They were told that this experience could help them to learn to solve problems better, which could be applied to other course projects they would be assigned. They were also told that training would be provided by the researchers and TAs so that they would know how to use the program when they came to the computer lab. This was done to alleviate possibilities of student unfamiliarity and/or anxiety about the use of computers.

During the second and third week of the pre-training phase, subjects completed a hands-on isopod lab experiment during their regularly scheduled lab divisions. At the same time, the sign-up sheets for the computer lab schedules were posted so that subjects would have 3 weeks to sign up for the computer labs. Each subject was required to sign up for two computer sessions with 2 hours each session. TAs were instructed by the researchers on how to train subjects from different treatment groups to respond to different cues. The instructions for the training were given to all of the TAs. Students were randomly assigned within divisions to each treatment group by the researchers, and the TAs were also informed of the names within each treatment group.

During the fourth week of the pre-training phase, student training on how to work with the programs and how to answer cue questions were conducted by the researchers and TAs in their regular lab sessions. The random assignment within divisions gave approximately 7 subjects per treatment group within each division.

During the treatment phase, eighteen Mac IIcx computers in a computer lab were used. Each computer was equipped with the four versions of the program corresponding to the three treatment groups and one control group. Each version required subjects to enter their own passwords to access a specific treatment. The password was given to the subjects during the pre-training session. By assigning the passwords to each student, the treatments were effectively isolated, preventing any opportunities for mixing the treatments. The researchers supervised the lab across all sessions to make sure that everything ran smoothly.

During the post-treatment phase, subjects were informed about the real nature of the project and were told that treatment was manipulated. They were encouraged to practice with different versions of the program so that everyone was exposed to the same versions of the program to reduce the possible effects caused by the manipulation in their performance on the course final exams.

Data Collections and Analysis

The data collection was divided into three stages, pretest data collection, on-line data collection and posttest data collection. Three weeks before the treatment, all of the subjects who signed up for the project were given pretests on near and far transfer problem solving. The on-line data was collected by Screen Recorder™(Farallon, Inc.) running at the same time when selected subjects were working in the program, as well as information which the program itself recorded to disk
(student responses to the cues and time on task). Three subjects from each treatment group and the control group were selected randomly. No subjects were interviewed during the treatment time.

As soon as the subjects finished two computer lab sessions, they were given the posttests on near and far transfer. The content was exactly the same for pre and posttests except that the orders of the questions had been changed. Eight subjects from each of the treatment and control groups for a total of 16 were selected for interviews right after they finished the near and far posttests. Five questions were used to direct the interview, and the same questions were asked across groups. They were 1) how subjects responded to the different cues; 2) how the cues affected the process of on-line task problem solving, 3) why some subjects did not respond to the cues; 4) whether the subjects asked themselves the same questions during the transfer problem solving; and 5) how the experience affected subjects' confidence and task interests. Refer to Appendix 4 for the sample protocols from each group.

The data was analyzed both quantitatively and qualitatively. One-way ANOVA and post-hoc Newman-Keuls were used to measure posttest differences among groups. Paired sample t-tests were used to measure the pre and posttests differences within groups. A random sample of 6 protocols from each group were coded for the cue response content by two independent raters. Interrater reliability was checked to be sure that subjects in the different treatment groups were in fact responding to the type of information that was requested in the question cues. The qualitative data were analyzed within each group to find the patterns of subjects' responses and learning processes based on their responses to the interviewer, and the student task designs were analyzed through a constant comparison process for any subgroupings.

Results

Quantitative Findings

To test the main hypothesis that all of the groups would perform equally well on immediate near transfer test, and that the metacognitive group would outperform all of the other groups in immediate far transfer test, analysis of variance (ANOVA) was used to compare performance across the groups on near and far transfer measures. Refer to Table 1 for the means and standard deviations for the pre and post measures on dependent variables among groups. There was no significant mean score differences among groups on the pretest of near or far transfer. Neither were significant mean score differences found among groups on posttest near transfer and the average time spent on the training task. However, the ANOVA for post far transfer tests indicated there was a statistically significant main effect among groups: $F\,(3,\ 84) = 5{,}95$, $p < .001$. Student-Newman-Keuls (SNK) was chosen for post hoc paired comparisons contrasting group means. Results of a post hoc SNK showed the order of the group means (in descending magnitude) in post far transfer (Refer to Table 2). Means which were not underlined by the same line were significantly different from each other. The finding suggests that the metacognitive group outperformed all of the other groups in posttest far transfer. The cognitive, affective-awareness, and control groups were not significantly different from each other. The main hypotheses were supported.

Table 1: Individual group means and standard deviations for dependent variables of pre and posttests on near and far transfer:

Variable	Group	N	Mean	Std Dev
Pre-Near	Affective	21	15.619	2.706
	Cognitive	20	15.550	1.8129
	Control	23	16.239	2.1313
	Metacog.	20	15.925	2.7012
Pre-Far	Affective	21	2.380	1.5961
	Cognitive	20	1.950	1.5035
	Control	23	2.043	1.637
	Metacog.	20	2.150	1.785
Post-Near	Affective	22	16.59	2.338
	Cognitive	21	16.69	2.337
	Control	24	16.39	3.65
	Metacog.	21	18.09	1.505
Post-Far	Affective	22	2.318	1.728
	Cognitive	21	2.523	1.364
	Control	24	1.708	1.366
	Metacog.	21	3.476	1.123
Time	Affective	15	77.46	24.12
	Cognitive	15	70.00	18.40
	Control	17	80.29	33.79
	Metacog.	17	67.58	18.12

Table 2: Results of the Post Hoc SNK contrasting group means on post far transfer test:

	Meta	Cognitive	Affective	Control
M	3.476	2.524	2.318	1.708

The differences between pre-post mean scores, standard deviations, T scores, and p values on near and far transfer within groups are listed in Table 3. The results indicate that metacognitive group was the only group which had significant differences between pre and posttests on both near ($p <.01$) and far transfer ($p < .05$). The closest to significance in pre and posttests on far transfer was found within cognitive group ($p = .07$). Affective and control groups did not have significant differences between pre and posttests on both near and far transfer.

Table 3: The differences between post-pre mean scores, standard deviations, T scores, and p values on near and far transfer within groups

Groups	Means (post-pre)	Std Dev.	T Score	P-values
Affective-awareness				
Near	.928	3.15	1.35	.192
Far	-.095	1.94	-.0224	.824
Cognitive				
Near	1.025	3.53	1.29	.210
Far	.65	1.56	1.85	.07
Control				
Near	.260	4.77	.262	.79
Far	-.260	1.91	-.654	.51
Metacog.				
Near	2.125	3.30	2.87	.0096
Far	1.4	2.32	2.69	.0144

Qualitative Findings

Immediate post task interviews, on-line data collection, and student task design analysis were used to answer the two qualitative research questions: 1) how subjects responded to metacognitive, cognitive and affective cues, and 2) how metacognitive, cognitive and affective cues influenced the students' task designs in the hypermedia system during the training.

To answer the first question, coding consisted of classifying students' responses to each question cue into one of the 3 levels of focus. The following is a list of the categories used in the coding of students' responses to the different question cues embedded in the hypermedia-based simulation program:

A. Process-Oriented Responses:
1. Planning (one step ahead, two steps ahead, etc.)
2. Monitoring (recognize right/wrong choices and why)
3. Subgoaling ("I decided to test that after I finished this because...")
4. Evaluative ("This experiment seems to be working because...")
5. Modifying ("I realize that I need to replicate what I have got in the first trial to draw more reliable conclusions.")

B: Cognitive-Oriented:
1. Stating specific rules for the problem ("the experiment needs to control variables, etc.")
2. Stating goals of the problem ("test how light and moisture affect isopod behaviors")
3. Recognizing the current state of the problem solving (" I got this answer right"; "my second experiment yielded right answer")

C: Personal Feeling-Oriented:
1. Positive ("I feel OK, fine, confident, etc.")
2. Negative ("I feel frustrated"; "It was too confusing")

To look at how subjects in the different treatment groups were responding to the questions that were asked in the program, a random sample of 6 protocols from each of the treatment groups was coded for the content by two independent raters according to the categories classified above. The summary consisted of the number of responses judged to be a member of each category for each question cue by each subject. A grand summary for each treatment was then calculated by each rater. The interrater reliability indicated 90% agreement. The differences were resolved by discussing the responses in question and deciding upon agreed-on judgments.

The total percentage of the responses made in each major category by each group was then calculated and compared to find out whether any of the groups differed in terms of the content of their responses. It appears that each group focused on the appropriate level of information requested by the questions (see Table 4). The affective subjects gave 96.5% feeling-oriented statements, 3.5% process -oriented statements and almost no cognitive-oriented statements. Among feeling-oriented statements, 65% were rated as positive and 35% of them were negative statements. Cognitive subjects gave responses that fell into the problem-oriented category (rules, goals, and problem state) 85.7% of the time. 14.3% of the time they made process-oriented responses and they almost made no feelings-oriented statements. The metacognitive subjects gave 72% of the responses that fell into the process category, 21% of the responses fell into problem or cognitive level and 7% fell into feeling levels.

Table 4: Category percentages for each group

	Affective	Cognitive	Metacognitive
Process	3.5%	14.3%	72%
Cognitive	0	85.7%	21%
Personal	95.5%	0	7%
Total	100%	100%	100%

In further analysis of the interview data, it was found that metacognitive subjects were involved more in the reflective processes. When they reached the solution, they were not just satisfied with it, but went further to find out why it was right or wrong. For example, when asked to summarize how the questions affected the whole process , one student responded "I think that they really made me go back and look at it and check myself to see that I was doing them right and really looked at my experiments to see how the results were turned out .*Otherwise, I might just finish and not go over it"* (emphasis is the authors'). Another student said that these questions helped her to " question further about [her] conclusions, like why. They made [her] make sure that they were valid enough". When this same student was asked if she would do anything differently if she were not asked the questions, she responded " Not really. I probably would not understand the processes I went through this well. I would just be satisfied that I got them right" In fact, most people from the other 3 groups were just happy to get the right answers and stopped there. One student in the cognitive group summed this up well . She said: " I did not really ask myself anything at the end. I was just glad. I knew I was correct."

Additionally, it appeared that while solving far transfer problems, metacognitive subjects continued to ask themselves questions similar to those presented in the computer program. This was not indicated by other groups of subjects. One student in the metacognitive group stated "Yes. I did go through the similar processes. I asked myself at the first place why I knew my results and setting up the experiments are right, why was I confident that I got a certain part right because I remembered my computer experiences". This response is characteristic of 11 of the 14 metacognitive students interviewed.

Affective subjects reported that awareness of on-task feelings helped them realize how they were doing in the problem solving process. If they were aware that they were frustrated or nervous, they felt that there must be something wrong with their performance. But many of them reported that they did not know what was wrong or how to fix it. ("It made me think about how I was solving the problem by realizing how I was feeling at that moment. But the question did not help me solve the problem better. Because they did not help me find out where is my problem and how to solve it.") Their responses told us that the awareness of emotion state is not sufficient to enhance the problem solving performance.

During the interview of control subjects, most of them indicated that they were very confused all the time and they needed more help. They felt that decision-making was the toughest part in the whole process. They were glad that feedback was given at the end to help them realize that they got right answers. "I feel very confused the whole way through. I wish I had more help. I was not sure if I was right or wrong. The decision-making part was very hard on me." Overall, subjects across groups reported increased interest and confidence in using computers. Many of them said "I like computer experiments. It saves time and mess.(metacognitive group)..."; "I like computers and I would feel more confident if I have to use it again..(Cognitive group)."; "I think that it was very neat that I could visually see what was happening in my experiments. I become more confident in using computers after this hard (control group)"; and "I like computers and wish to have more experience with it. (affective group)".

To answer the question of how metacognitive, cognitive and affective cues influence students' task design in the hypermedia system during the training, a constant comparison analysis was performed . The students were asked to diagram their designs on paper immediately after finishing the computer program. Figure 1 shows a visual representation of the process of forming the groups. In the end, the designs fell into one of four (4) large groups: designs exactly like those on the program; designs which did not show any separation of variables; designs which showed a separation of variables, but did not test the two variables against each other; and designs which tested the variables against each other. The group which showed separation of variables was subdivided by number of variables tested (1, 2 or 3) and whether or not those in the 2 variable category ran replications or not. This resulted in four subcategories in this group. The group which showed some testing of the variables against each other was also subdivided into those who only compared the two variables, and those who both isolated the variables and compared them. This last group was subdivided further as to whether the testing of the variables against each other was correctly designed or not, and if the correctly designed one ran replications or not. This gave a total of four subgroups in this category, making a total of ten possible groups of designs

In each of these ten groups, the students were clumped as to which of the four experimental groups they participated in. Numbers of students in each group were converted to the percentage of the total number of students from their treatment group, so comparisons could be made across treatment groups. See Table 5 for these results.

The ideal task design would be to both isolate variables and correctly tested them against each other(group 10) . If we do not consider whether the student carried out replications, then 19% of the cognitive students are seen in this group, 6.60% of the affective students, 4.7% of the control students and 4.5 % of the metacognitive students.

FIGURE1:
A Visual Representation of the Resulting Groups for Analysis of Student-reported Designs

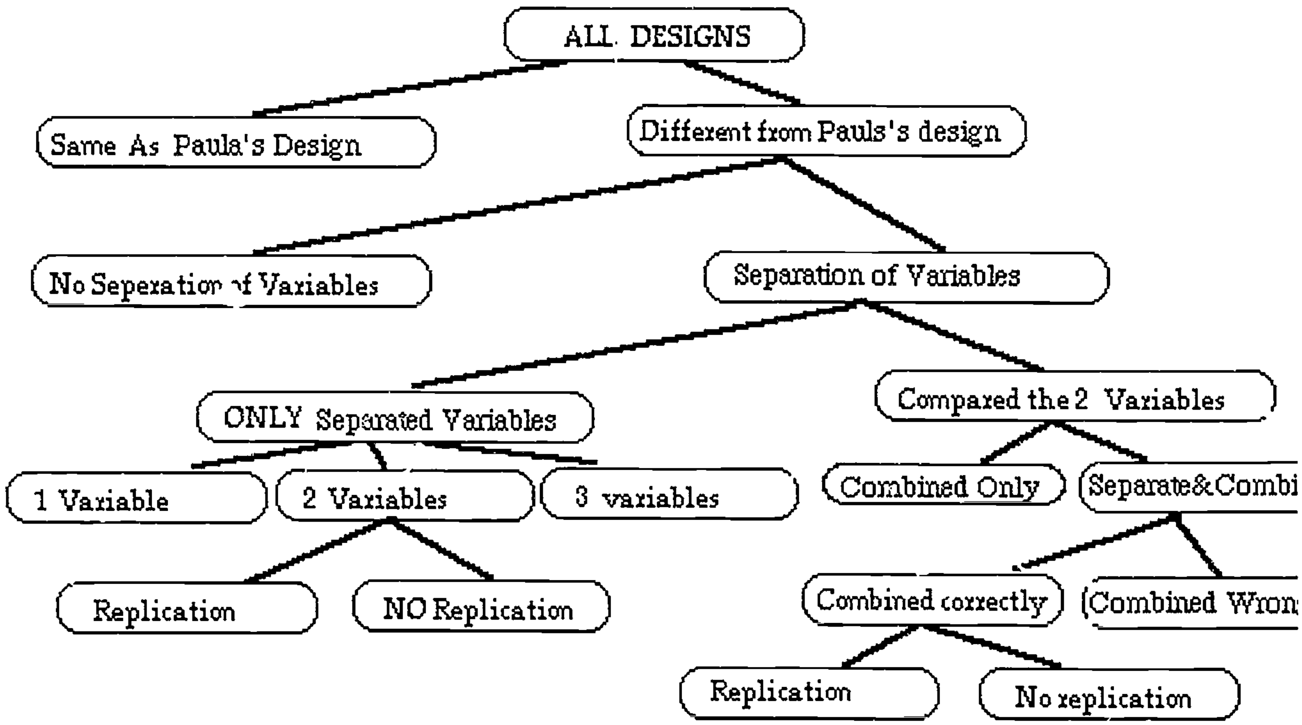

Table 5: Comparison of Group Compositions for Design Analysis:

group	1	2	3	4	5	6	7	8	9	10
control	4.70	4.70	9.50	9.50	47.00	0.00	9.50	4.70	4.70	0.00
affective	0.00	13.30	13.30	6.60	33.0	13.30	13.00	0.00	6.60	0.00
cognitive	4.70	4.70	19.04	19.04	28.50	0.00	0.00	0.00	9.50	9.50
metacog	9.00	4.50	4.50	27.00	32.00	4.50	0.00	4.50	4.50	0.00

Note: group numbers in this table refer to group numbers designated in Figure 1

Conclusions

On the posttest of far transfer, the metacognitive group scored significantly better ($p < .001$) than any of the other groups. In the within-group t test analysis, the metacognitive group was the only group which showed statistically significant increases from the pretest to the posttest on both near and far transfer tests. This shows that the metacognitive question cues can positively affect the way in which students approach problems, and that this effect continues afterward for problems which are only distantly related to the training problem.

More evidence for this carryover of thought processes is revealed in the student interviews. When asked about the transfer tasks, students in the metacognitive group replied that they continued to ask themselves questions similar to the ones in the computer program, while the other cued groups did not. One control student, when asked about the post test answered " For the most part I knew I was right, so I did not question myself." Another student in the affective group, when asked if she asked herself anything similar to what she was asked on the computer program, replied "No. Not really. I did not really ask myself anything like that." During the interviews, the metacognitive students also spoke of the fact that if the cues had not been there, they would not have stopped to plan as well as they did, nor would they have stopped to contemplate why they got correct or incorrect answers. For example, one student when asked if she would do the same thing if she had not been cued replied "No. I wouldn't. I may just be satisfied with the fact that I got it." The same student, when asked if the questions affected her confidence, interest or motivations, said "Yes. They made me feel good because I got them all right and I did the experiments right and understand the whole process better..." She stated that if she had not been asked the questions by the computer, she would not have felt the same way, "because those questions helped [her] to understand."

There was variation within the groups, however, and some students replied that even though they were forced to give some reply to the cues, they did not give much thought to the cues. One student commented, "basically I just used pre-knowledge from the lab we originally did, the hands-on experiment. I used prior knowledge to decide what I was going to do next as I had originally done." One student's answers indicated that although she said she ignored the cues, she may have been using them. When asked if she had ignored the questions, this student replied, "Exactly. Those questions did not help me. *But they did provoke me to think what I would do next.* But I could not find the direct relationship between what I have thought and my understanding of the whole process" (emphasis is authors'). All of the preceding quotes were from the students in the metacognitive group. Although the responses varied among these students, the majority of them (11/14) interviewed indicated that these cues caused them to stop, reflect and do something different than they would have without them.

Although the qualitative analysis of students' task designs seems to contradict this "good news" by showing that, on average, the metacognitive group did worse on their task designs, we are reluctant to give these data heavy weight for several reasons. First, the designs were self reported by the students after they completed the computer activity. Within the "recorded" subset of students, when we compared their self-reports of their task designs with what actually happened while they were on the computers, 50% of the students either under or over represented the training task designs which they had actually completed. Second, after watching the screen recordings, we found that many of those students who were recorded also designed tasks which were not actually run, or changed the design of the task before they ran it. The students' self-reported data were not complete. The data tended to show only a segment of the task designs and did not accurately show the changes that students made during the process of designing the task. In analyzing these data, it is often not possible to tell if the students' diagrams represent an initial plan or the end result of the entire process of computer task design. It can be concluded from this experiment that retrospective qualitative data are not as accurate as on-line process data, and are not appropriate for collecting process data, especially when the data can not show the progress or changes made during the process.

Therefore, even if the metacognitive group task designs were less comprehensive than those of the cognitive and control groups, we feel that this is not an indication that all of the cues failed (since the metacognitive group went on to outperform the other groups in the transfer test), but may mean that some of the cues failed. One cue that may not have been successful for the metacognitive students' task design was the first cue ("What's your plan for solving the problem?"). This cue asked the students to detail their plans for the experiment.

All of the students came to the experiment with strong preconceptions carried over from the experiences in the hands-on lab. Unless an event occurred during the process of the computer simulation to jar them out of this preconception, they continued to solve this problem as they did in the lab. For some students, reaching wrong answers or unexpected cues made them confront their preconceptions. Since almost 60% of the metacognitive group ended up in one of the two groups which only tested two variables independently (see Table 5: 5&6), it may be that the cue which asked them "What's your plan for solving the problem?" was not different enough from what students were thinking at that moment to elicit a strong response and thus break them out of their preconceptions.

This hypothesis is further supported by the interview data. When asked how they reacted to the first cue, most of the metacognitive students indicated that the main effect this cue had was to cause them to stop and think, or to slow down. For example, one student responded, "it made me think about it for a second before I took any actions. During that second it reminded me of what I did in class." However, while doing the hands-on lab experiment, the students were never required to test variables against each other. The problem-solving process they went through in the hands-on lab could not be applied to the problems posed in the computer program. Thus, the student's response was not appropriate. When asked if they would have done anything differently if they had not been given this cue, most of the metacognitive students answered that the only difference was that they would not have written down their plan, or that their plan might not have been so detailed. Another student responded "I put 'plan to test variable individually'. I did not make a very detailed plan." In all of these cases, we see that the first cue did not succeed in breaking these students' preconceptions, but allowed them to continue their task designs with their preconceptions intact. This might explain why so many of the metacognitive group had task designs which only tested the two variables (light and moisture) independently, and why they did not go on to test the two variables against each other.

Contrasted to the metacognitive students' responses to the first cues, the cognitive students' interviews showed that in order to answer their first cue ("What variable(s) are you testing for?") they had to do a lot of metacognitive thought. For example, one student said, "They really made me think. They really did. They helped me along to see what I need to do in an experiment. They kind of making me think about exactly what variables I need to test and how many I am supposed to have in the experiment." Another student said, " They really made me think how to set up certain things. And it just made me think more consciously about what I was doing." This tells us that although the responses to this cue were cognitive
(light,moisture, etc...), students had to go through a metacognitive process in order to respond to this cue appropriately. In fact, within the cognitive group, 9 of the 12 interviews indicated that the cognitive students went through such metacognitive-oriented processes when responding to the first cue.

We can conclude that a cue which induces a metacognitive process can have a significant positive impact on students' problem solving processes. In the case of the first cue, the metacognitive response was actually found in the cognitive group. Consequently, their task designs were also much better than all the other groups. However, this single cue was not strong enough to guarantee that the rest of their thought processes continued to be metacognitively oriented, and the cognitive students failed to show far transfer.

Even though the first cue in the metacognitive group failed to induce metacognitive processes, the metacognitive students subsequently received many more cues which actually induced metacognitive processes (refer to Table 4 for the category percentages for each group). The high percentage of process responses generated by the metacognitive subjects suggest that the majority of the metacognitive cues successfully engaged students in metacognitive processing. This allowed the students to continue a process of "self-questioning" during the posttest, which may have helped them score significantly higher on the posttest of far transfer. Therefore, what students actually transferred were the metacognitive processes rather then the content-specific information. These processes made students focus on and become consciously aware of the solution components. By focusing on a process level, subjects were able to attend to information regarding the way in which they solved a problem. This finding is consistent with what Berardi-Colleta (1990) found in her study. She concluded that the process-focused groups are not only transferring knowledge to the new task, but that they are also transferring an approach to the new problem.

Since all groups claimed to have planned, regardless of the type of cues, we propose that metacognitive planning needs to be carefully interpreted by the researcher. Mere planning was not sufficient to insure correct and complete task design. In order for task design to be correct and complete, these "plans" had to be coupled with active metacognitive processes such as monitoring, reflecting and evaluating.

The issue of how these cues affect the students' task design process needs to be further explored. Given our experiences here, we would recommend that the process data be collected concurrently and be as detailed as possible. We would also caution that researchers and teachers need to be careful about their choices of cues, ensuring that the cues are attention focusing,and strong enough to break previously held preconceptions, as well as inducing metacognitive processes. Finally, the emphasis in problem solving research has placed on needs to shift to focus on human problem solvers as "memory banks" to humans as dynamic,active processors of their own learning experiences that are continually acquiring information in the learning process.

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APPENDIX 1:Cues Embedded Within the Computer Program

Affective Group	Cognitive Group	Metacognitive Group
Location One: after reviewing Paula's experiment and problem statements, and before any selections have been made		
Rationale: check feelings and mood before task	**Rationale**: review the goals and rules of solving the problem	**Rationale:** make plans for solving the problem
(1) How are you feeling right now in dealing with this problem?	(1) What variables are you testing?	(1) What is your plan for solving the problem?
Location Two: after selecting all of the materials and supplies, and before conducting the experiments		
Rationale: check on-task feelings	**Rationale:** check actions against goals and rules of solving the problem	**Rationale:**reflect on the actions have been taken and plan for the next step
(2) How are you feeling right now?	(2) What materials and supplies have you selected? (3) What are you going to test?	(2) Why did you select those materials and supplies? (3) How are you deciding what to do next?
Location Three: after finishing all of the experiments and drawing conclusions, and before the feedback was given		
Rationale:check post-task feelings	**Rationale:**encourage self-discovery of the current sate of the problem solving	**Rationale**: monitor and evaluate the effectiveness of the process of the problem solving
(3) How you feeling right now?	(4) What conclusions can you draw about the variable(s)?	(4) How did you decide that you have had enough data to make conclusions?
Location Four: after providing the feedback		
Rationale:check the processes of the feeling change	**Rationale:**check the final performance by knowing the number of the experiments that are useful or not useful	**Rationale:**do not be satisfied with right or wrong answers, find out why they are right or wrong, build up a repertoire of strategies for further modifications of the processes
(4) How are you feeling right now comparing to when you just got started?	(5) How many of your experimental designs gave useful data? or How many of your experimental designs did not give useful data?	(5) What part of your experiments led you to the right or wrong conclusions? *How are you going to fix it?(ask only if the conclusions are wrong.)

Appendix 2: Teacher-Made Near and Far Test of Problem Solving

NAME____________________________________ **DIVISION**_______________

BIOLOGY 205 LAB QUIZ FALL 1992

<u>INDIVIDUAL QUIZ</u> - ISOPOD LAB

1. What environmental conditions do isopods "prefer?" (4 pts.)

2. Explain the basis for your conclusions about isopods' "preferred" environmental conditions. (6 pts.)

3. Suppose you had the following information for the isopod lab:
   Ten isopods were placed in a trough in section 3, and after ten minutes, the following results were noted as diagrammed below:

WET **DRY**

*	*		* * *	* * * *	*
1	2	3	4	5	6

Based on the information given above, answer the following questions:

a. What is the variable in this experiment? (1 pt.)

b. How would you describe the response of these organisms to this variable (<u>based on the diagram above</u>)? (2 pts.)

c. What is random behavior? (1 pt.)
d. Do you see random behavior in the diagram above? <u>Explain your answer</u>. (3 pts.)
e. What could you do to validate your results? (3 pts.)

4. **QUESTION (6 POINTS TOTAL) (FAR TRANSFER PROBLEM)**
   The elementary school in which you teach seems to have an unusually high number of hyperactive students. In fact, of the 100 students in second grade, 50 of them are hyperactive. Different groups of adults have proposed various ideas to explain this. The parents say that the **<u>peer influence</u>** causes them to be hyperactive. The principal thinks that the **family environment** is the cause of their hyperactivity. The teachers, on the other hand, say that **<u>diet</u>** is the source of the condition. You have been asked to design an experiment that would determine which one or more than one of these explanations is correct. Explain how you would set up this experiment to determine the cause or causes of the students' hyperactivity. (Use the back of this sheet if you need more space.)