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DESIGN AND DEVELOPMENT OF MIST—A SYSTEM TO HELP STUDENTS DEVELOP METACOGNITION

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ABSTRACT

Metacognition in Studying from Texts (MIST) is a system that deals explicitly with helping students develop metacognitive skills. MIST has been built with three important features to foster metacognition—a process-based interface and support for collaboration and reflection. This article also reports an evaluation of the system especially related to the design features. It was found that students of high ability used the interface in interesting ways and the intervention was used more productively by them. Students of low ability, on the other hand, had some difficulties in using the various options offered by MIST. These findings are discussed and improvements to the system are suggested.

Interest in metacognition in computer-based systems has been relatively recent. As expressed by Dillenbourg, the process of becoming aware of one's own knowledge or one's own cognitive processes, i.e., the reflection process, is a topic of growing interest among researchers on metacognition and among Educational Computing Systems (ECS) [1]. Attempts to help students reflect on and regulate their learning with the help of computer systems have mainly taken three forms: 1) manipulating the interface, 2) collaboration, and 3) reflection—each of these being used as a means to foster understanding. TAPS, Teaching Arithmetic Problem Solving [2-4] and TiPs [5] are designed to help students solve arithmetic word problems. TAPS provides users with a graphical interface with tools for constructing problem trees. Students' problem solving routines are made explicit by constructing such trees and their understanding of the concept is fostered by graphical reification. This enables students to see their solutions so that they are then open to manipulations and discussions. STUDY is designed to promote in learners both a knowledge about the content and knowledge about the cognitive strategies [6]. The system consists of an interface with menus that help students to set goals, choose study methods, etc. The idea is that directing one's own learning will lead to greater participation on the part of the learner thus resulting in enhanced understanding and also better memory. Students can thus take an increased initiative in learning. Winne explains the role of STUDY as a means to examine how learners exercise and develop self-regulation in the absence of scaffolding that might be provided by teachers, peers, or advanced technologies [7].

Metacognition in ITSs has taken another interesting form. This is based on the Vygotskian concept that understanding one's own learning is enhanced by interaction with others during learning. There is evidence in the psychological literature that learning with a peer helps one to understand one's own learning. The social context thus supports the individual's learning [8]. Chan and Baskin in their "Integration Kid" put forth the notion of a computer based learning companion who learns alongside the student [9]. There is thus a trilateral relationship between the teacher, the student, and the companion. The teacher's role is mainly to monitor the situation, i.e., to generate problems, explain with examples, offer comments, and intervene only when the student and the companion both fail to solve the problem. The student and the companion take turns in solving the problems—so that while one is solving, the other is watching, offering suggestions only when needed. Another attempt to have a computer based co-learner is by Dillenbourg who introduces a machine based co-learner [10]. This is based on the concept that mutual regulation leads to an internalization of regulation skills—i.e., it leads to self-regulation.

Collins and Brown suggest the use of reflection to help students develop metacognitive strategies [11]. Students can be shown performance of an expert to enable them to reflect and find their own mistakes. Records of the student's own performance may also help in self-monitoring. In Algebraland and Geometry Tutor, students are shown problem-spaces, i.e., abstractions of the problem solving process. Students are shown the states in the problem solving process that they reached and how they reached them. For example, in Algebraland the program forms a tree of the various steps that the student performs in order to solve the problem. However, as Dillenbourg describes, "the availability of reflection tools does not guarantee that users do indeed reflect on their learning experiences. We can only claim that the learners reflect if they perform some activities on the representation of their problem solving" [1]. Although the systems mentioned above do recognize the importance of metacognition, they do not explicitly help students to learn about the process involved in learning. It is important that students should be helped to concentrate on their learning, so that they understand the activities they are engaging in, and use this increased understanding across different tasks. Thus, instead of simply making reflection tools available, "or designing systems that compensate for metacognitive deficiencies by becoming increasingly directive," it is crucial that "we develop systems that support the learner's metacognitive activities (or, even better, that develop their metacognitive skills)" [1].

This article describes MIST (Metacognition In Studying from Texts), a system that deals explicitly with helping students develop metacognition. The article also reports an evaluation of the system especially related to the design features and the possible improvements to MIST. The theoretical basis of MIST is described first, followed by the empirical work and the results.

DESIGN OF MIST

Theoretical Framework

During the last decade and a half, there has been an increasing realization of the fact that in order for students to become effective learners, they should be *aware* of the process of learning and take *control* of their learning [12]. Metacognition, or learning "how to learn," is now recognized as a vital aspect of learning. Metacognition refers to one's knowledge concerning one's cognitive processes and products or anything related to them . . . metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in service of some concrete goal or objective [13]. Brown recognizes two important aspects of metacognition—knowledge about cognition and regulation of cognition [12]. The first, *awareness* or knowledge about cognition, is the knowledge learners have about their own cognitive resources, themselves as learners and about the learning tasks. The second, *control* or regulation of cognition, consists of active regulation skills such as goal setting, planning one's next move, checking, evaluating, and modifying. Brown emphasizes that the goal of instruction should be to enhance students' conceptual understanding of the processes that they employ during learning, to help them to monitor and regulate these processes, thereby producing more insightful and intentional learners [14]. According to Brown, a great deal of academic learning, though not everyday learning is active, strategic, self-conscious, self-motivated, and purposeful. Hence learners operate best when they have insight into their own strengths and weaknesses and access to their own repertoires of strategies for learning [15].

The research described here concentrates on metacognition in one important area of learning, that of studying from texts for reasons given below. Studying from texts is a complex process. According to Fischer and Mandl, the requirements demanded of a learner while studying from texts are quite severe [16]. This is because the major goals of learning from texts are to work out the core information contained in the texts, to reduce it to its main ideas, to comprehend it, and to integrate it with the learners' existing body of prior knowledge. In addition to this, learners should be able to retrieve the knowledge quickly and without effort at the right time and place. It is thus a very demanding task and it is not surprising therefore, that so many high school, college, and even university students report learning difficulties [16].

Early work on metacognition has been in the area of studying from texts and Brown, Bransford, Ferrera, and Campione's tetrahedral model for studying from texts (adapted from Jenkins' model) has been the main theoretical basis of this research [17]. This model describes learning from texts as an interaction of four factors—text, task, skills, and the learner herself. According to Brown, Armbruster, and Baker, learners can be made aware of such features of the text as text difficulty, relative importance of the various propositions in a text, and the inherent structure of the text [18]. Students are faced with different types of tasks in an academic setting and it is thus important for them to consider the task, i.e., the purpose for which they are reading a particular text, and allocate resources accordingly. Thus, a student reading to find specific information would have a different strategy for learning than one who is reading to get all the details. In addition to the text and task, the learner herself is an important factor affecting metacognition. The learner's own past knowledge, strengths and weaknesses, skills, etc. is an important aspect of learning. Activation of prior knowledge helps to improve learning by helping the learner associate the present learning with something she/he already knows. The final factor that contributes to metacognition is the knowledge about study strategies. In order that students use the strategies that they learn during training, students should also be told about when and why a particular skill should be used in addition to knowledge about how to apply a skill.

Main Features of MIST

Process Based Interface

The main focus in the design of MIST has been to understand what students actually do during learning from texts and to provide methods to help them become more self-aware while they are engaged in the activity. Thus the processes or activities of the learner have been more important than the product or performance measure which is a result of that doing. According to Brown, in order to train students to think about what they are doing, they should be taught to ask themselves 1) Stop and think, 2) Do I know what to do, 3) Is there anything more I need to know before I begin, and 4) Is there anything that I already know that will help me [19]. Students can be taught to think by making them interrogate themselves [20]. However, students need to be prompted in order that they remember to interrogate themselves. Hence it is important to have an on-line monitor that keeps track of the students' processes. What is required is a mechanism for "eliciting" self-awareness and -control. This can be achieved by manipulating the students' learning environment in a way that gradually "engineers" the development of metacognition [21]. Students should therefore be prompted in such a way that they will be forced to stop and think and regulation will "evolve" as a result of the interaction. For example, KIE uses metacognitive prompts which are more context dependent, including self-monitoring prompts to help students reflect on their learning [22]. With this in view, MIST was built with certain distinctive features.

MIST's interface and interactions with the students are based on the processes that student might engage in during learning. Such an interface is based on the assumption that "making covert, abstract processes visible, public, and manipulable, would serve as a necessary catalyst for reflective metacognitive activity" [4]. Thus the interface is based on the activities that the students would undertake during learning and students can choose from a range of activities. To build a system that will help students to learn effective strategies in the context of their academic goals was one of the prime concerns of this research. Researchers such as Derry and Murphy [21], Duffy and Roehler [23], and Garner [24] emphasize that in order for students to use the skills with understanding and also subsequently to use the skills in novel learning situations, it is important that students be taught the skills in context. Psychologists have differentiated between embedded and detached training. By embedded is meant that students are taught the skills within their current academic context. A detached approach is that in which strategies are not clearly related to such a context. It is generally believed that students should be taught skills within a meaningful context [25].

With this in view, MIST was built to be "subject domain free" and not "subject domain specific." MIST was designed in such a way that students can come to it with any text from which they wish to learn and use it as an "advisor" to help them learn "how to learn." One of the greatest advantages of this system is that, since the system depends on, and is seen (by the students) to depend on the students' judgment about the type of text, choice of skill, about what to do next, at every point in the process of learning, the system induces the student to think and then proceed. Thus, in a way, the system allows the metacognitive knowledge to evolve as a result of experiences that the student acquires during learning. If the students' judgment of text is wrong and hence the resulting choice of skill is wrong, the student will realize this on her own with the system helping her to think about alternative ways. This kind of interaction will thus be helpful in developing the thinking skills that will assist the learners to monitor the process of learning. Another major advantage of this system is its applicability. It can be applied to any text which the student brings and this increases the possibility that the student will relate the knowledge gained by the interaction to real life learning. Relating knowledge of strategies to their current academic goals will increase the possibility that students will generalize the skills to learning beyond the training situation.

It may be noted that although MIST does not have any specific knowledge about the texts that students wish to study from, it nevertheless has knowledge about the types of activities that students might engage in during learning from texts. Thus, interactions with students are based on the activities that students undertake during learning rather than on the subject domain that they are learning. It may therefore be said that MIST has knowledge about metacognition (control and regulation of cognition) rather than the specific subject domain, as explained in the next section. The system's interface is based on the meta-knowledge about the process of studying from texts, the activities that students undertake during learning. The first part of the system helps students become aware of the various cognitive skills that can be used, where, when, and how they should be used, and how they should pay attention to the different types of tasks and texts and activate any prior knowledge that they may have. In the second part of the system, students can choose options relating to planning, text processing or reading, and memory enhancing (organizing information). Students can engage in specific planning and monitoring activities. For example, students can plan and set goals, activate prior knowledge, set study time and plan the methods or skills that they will use. During text processing, students can engage in activities such as selecting main ideas, reviewing, and summarizing. They can engage in various organizing skills such as making trees, tables, nets, and also predict the types of questions that can be asked. By choosing the options, students are asking themselves questions which make them think about the activity of learning. Because it has knowledge about metacognition and not the specific subject domain, rather than providing feedback at the domain level, intervention by the system is at the meta level and is intended to help students think about what they are doing and why they are doing it.

MIST has been built as a two part system based on the two aspects of metacognition—awareness and control [12]. MIST is built in Supercard and runs on a Macintosh computer. Students interact with the system in pairs. The first part, a non-interactive browser, deals with making the students aware of the various factors affecting learning from texts. The second part, the interactive part of the system, helps the students regulate (control) their learning. In order for a system to help students learn about learning or studying from texts, the first thing is to make students aware of the various factors affecting regulation, i.e., knowledge about the task, text, learner, and study strategies. Awareness training being the first prerequisite of metacognition, the system's first important task is to impart knowledge regarding the different factors affecting metacognition. The first part of MIST is a non-interactive browser which helps students become aware of the four factors affecting metacognition in studying from texts. The browser is simply a network of screens implemented in Supercard. It has buttons for navigation but does not react to the student as an individual. There are three major topics in the Browser: 1) planning, 2) general skills, and 3) specific skills. Under planning is included knowledge about features of the text, the types of tasks (purpose of studying), and activating one's prior knowledge. Students are given information about the types of tasks that they could face (for example, studying for a gist or studying for details) and are also informed about the different nature of these tasks. They are informed about aspects of the text and are made aware of the fact that they should pay attention to the typographical cues of the text. They are also informed about how certain skills are more appropriate to certain texts—for example if the text compares attributes of different objects, then drawing a two-dimensional table would be an appropriate skill. Figure 1 shows some example screens from MIST.

The Browser also advises students to think actively about any prior knowledge that they may have about the text. General skills include skills such as skimming, finding main ideas, and underlining that can be applied to any text. Specific skills are more specialized skills such as making trees, semantic nets, writing a paraphrase, and making tables. Each skill is presented with examples. There are "example" cards attached to each skill which provide students with examples for the skill. The example cards also show the text that the skill has been applied to. Students can thus read about the different skills and the examples of that skill.

The interactive part of the system consists of a network of cards that are driven by the students' responses. The cards are grouped into three main topics—planning, reading, and post reading. During each of the stages the students choose options depending on the activities that they want to engage in. In the planning and the reading stages, the students' interaction is limited to clicking on the various activities on the screen. Students take turns to click on the options. Each student in the pair gets her own set of cards which are color coded for that student. However, during the post reading stage, students can work together on the computer screen to make trees, tables, nets, and outlines. The drawing tools provided by MIST are designed to help students draw lines, rectangles, circles, and write words or phrases. Students can also move the figures drawn by them or get rid of them. As indicated earlier, MIST is based on the activities undertaken during learning and hence the interface provides students with means to make the process explicit. Interactions are at a higher level (the process or meta-level) rather than at the domain level. Apart from trying to make the invisible processes "visible," MIST also attempts to structure the students' learning by helping them proceed through the stages and provides feedback based on their activities. During the planning stage, MIST offers students menus to:

- Set a goal or purpose
- Classify the text according to its features
- Allocate study time based on the text and task
- Think about and decide what methods will be appropriate for the current purpose
- Think about any prior knowledge about the text

By setting goals, thinking about the text and activating any prior knowledge, students are helped to become active participants in the learning. They are forced to think about what they want to do and how they want to do it. The two students

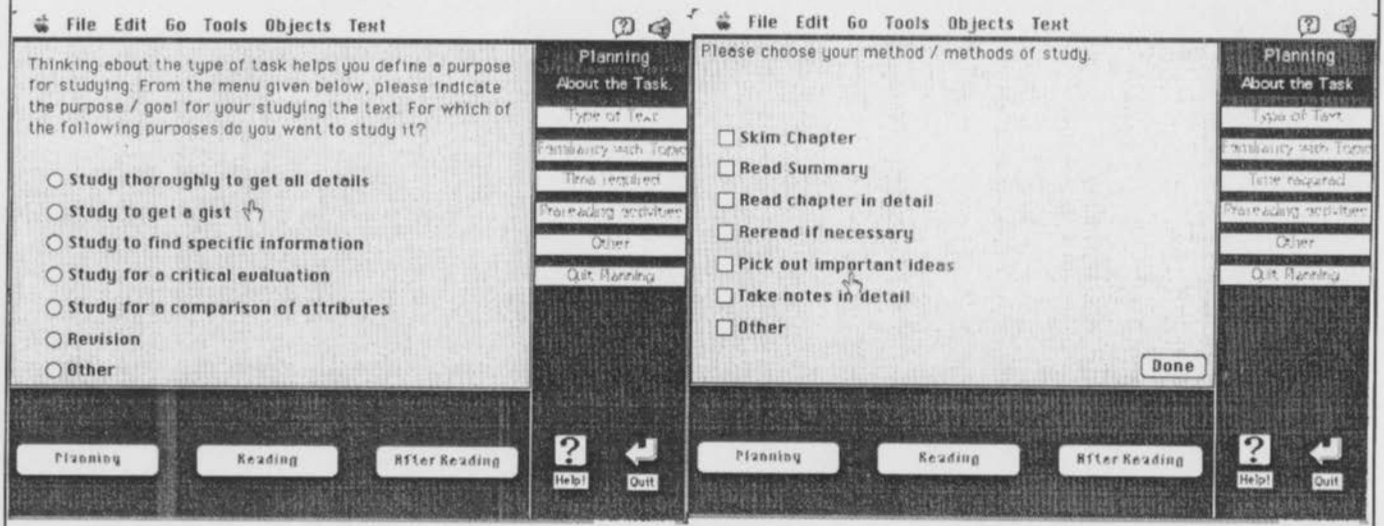

Figure 1. Examples from MIST. The first two screens show some menus from the planning stage. The second screens are examples of some of the options that students can choose in the reading stage. The last two screens are from the post reading stage in which students can use the different strategies and nets, maps, etc. on the computer screen.

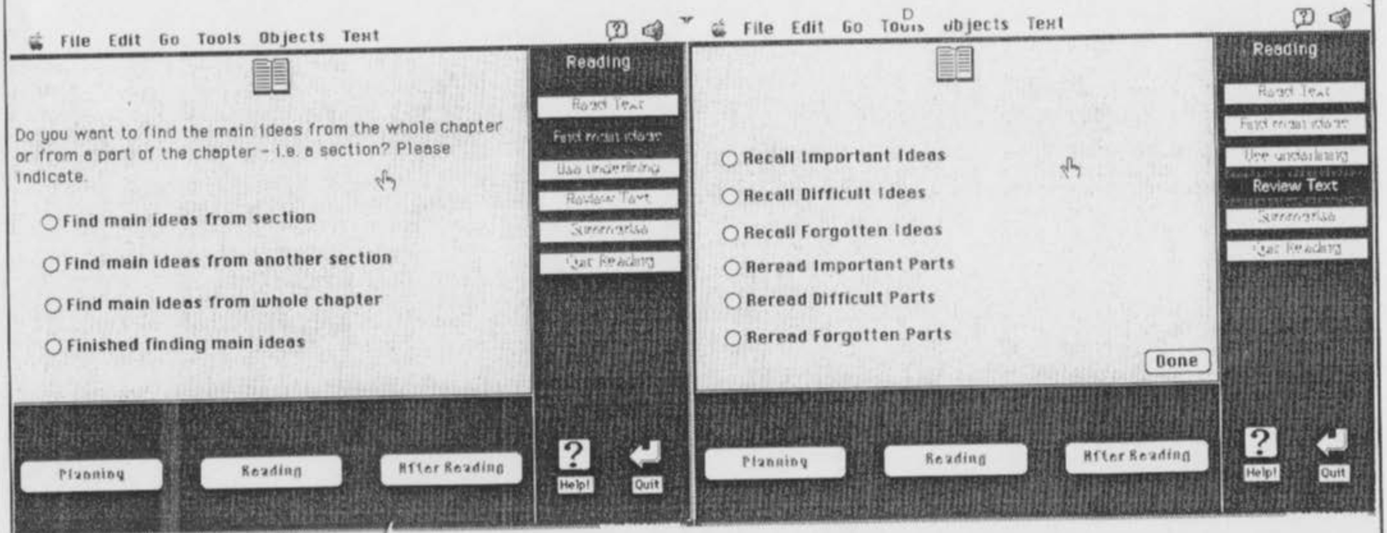

Figure 1. (Cont'd.)

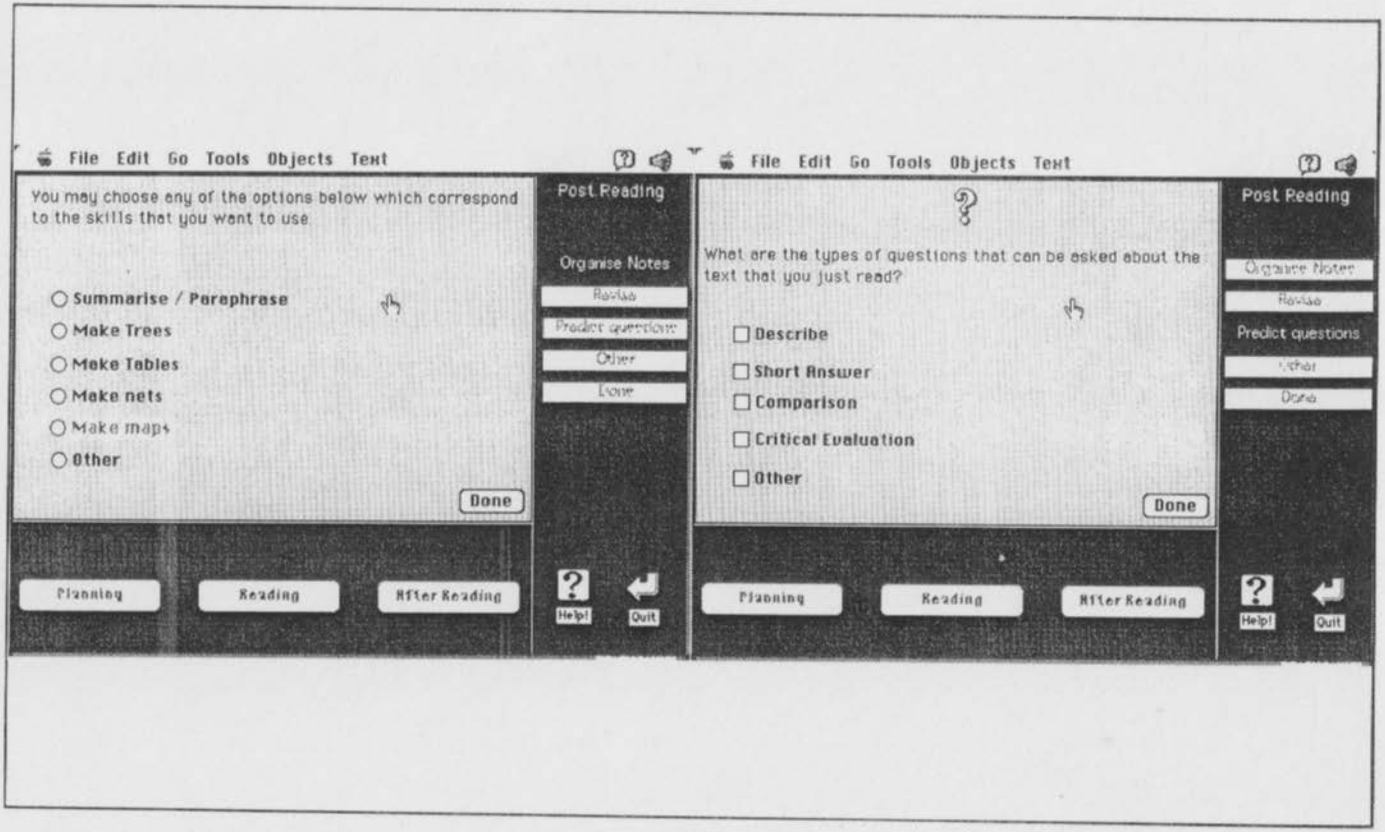

Figure 1. (Cont'd.)

take turns to choose the options during the planning stage. While one of them is making the choices, the other student is asked to observe. During the reading stage, students can choose from options such as:

- Read text
- Identify important points
- Summarize
- Review text

During this stage students actually read the text, find main ideas, review text, reread, etc. The work is done outside the computer and the system helps the students to work together by keeping a record of their choices and initiating interactions between them. The post reading stage offers students tools to construct trees, maps, nets, etc. Students can:

- Write a paraphrase/outline [26]
- Make two dimensional tables [27]
- Make trees/spider diagrams (used by many school students)
- Make semantic nets [28]
- Predict questions [8]

These activities are aimed at helping the students to organize their knowledge and are based on research on learning strategies as indicated above. Students can choose from the different skills and they can work together to make the trees, nets, etc. on the computer screen. When students choose a particular skill, a "floating palette" window with tools appears along with another window with a blank card where the students can draw. During this stage, students work together with one of them in charge of the mouse. After they have finished with a skill such as drawing a tree or a table, they are asked whether they think they have used the appropriate skill and whether they have included all the main points. This is to encourage them to think about what they have done and to give them an opportunity to change it if they wish. The figures drawn by each student are written in a file. Another option provided by the system in the post reading stage is "predict questions." Students can predict the questions that may be asked in a test. Predicting questions is done in two stages. First of all, they think about the *types* of questions—for example, they can predict whether they will be asked to write a short answer, a comparison, critique, or any other type. They then proceed to write the specific questions that may be asked. This is in some ways similar to the predicting in reciprocal teaching [8]. However, students using MIST also have the chance to think about the types of questions thus forcing them to think hard about the content of the text. Once again, the types of questions are recorded and the questions that students write down are written to a file. During this stage, students can also choose the "Revise" option to revise from their notes or from the textbook itself.

Collaboration

Another important feature of MIST is that students learn in pairs with support from the system. The importance of the social context in supporting an individual's understanding of her own learning (i.e., metacognition) was emphasized by Brown and Palincsar [8]. In recent years there has been a considerable rise in interest among designers of computer systems in exploring computer support for collaborative learning. There have been different levels and ways of using computers for collaboration. Many researchers emphasize collaborative forms of instruction [29-32]. Consequently there are systems that support human-computer collaboration [9, 10], and systems that support human-human collaboration with a computer [33]. Implicit in the numerous attempts at computer supported collaborative learning is the notion of providing more opportunities for reflection and understanding while learning. One of the main aims of the research described here has been to explore, in a more direct way, the use of collaboration to foster metacognitive understanding among pairs of students interacting with the computer system. MIST is built in such a way that students learn together, with the system providing support, until they acquire proficiency and become independent learners. Both the students interact with the menus on the screen. They learn together, cooperating with and helping each other. The system intervenes in such a way that the interest and motivation of each of them is maintained while helping them learn self-regulation skills. MIST's inability to comment on the specifics of the text is thus to a large extent compensated by having students interact with it in pairs. Student can help each other in choosing options such as classifying the text, choosing and applying skills. Thus, in a way, by helping each other they also help the system. In most collaborative learning situations, with or without the computer, students are just asked to learn together. It is considered natural for the more able students to help the less able. The guidelines that initiate the social interaction are not very specific. The spontaneous social process is allowed to take over. Although this is the most natural way in which students can learn together, Teasley and Roschelle point out that "the process of collaborative learning is not homogeneous or predictable, and does not occur necessarily by putting students together . . . collaboration does not happen because students are co-present" [34].

MIST keeps a record of the activities undertaken by both the learners (though it has no independent means of checking that what has been chosen is actually carried out) and uses this as a basis to *initiate* interaction between the learners by asking them specifically to help each other. Depending upon the progress of the learners it advises either one to help the other. As indicated earlier, having students learn together does not necessarily result in them collaborating with each other. Slavin explains the "free rider" effect in which some of the group members do all or most of the work while the others go for a free ride [35]. There is always the fear that the more able or dominant members will override the less able in social learning situations. MIST tries to reduce this problem by providing explicit instructions about how the students should help each other. More specifically, it instructs the students to either *clarify* or *explain* what they understand by the options on the screen. As has been emphasized by Guzdial, Konneman, Walton, Hohmann, and Soloway, self-explanations help students to understand the process [36]. MIST encourages the students to explain to each other during learning. For example, if both the participants S1 and S2 have finished with planning then MIST evaluates their performance. If evaluation indicates that S1 has chosen more planning activities and has shown more metacognitive understanding and S2 has not (and vice versa) then after first allowing S2 to read S1's performance summary it asks S2 to clarify what she thinks about the options presented on the screen. If S2 asks for help, then MIST asks S1 to explain first. In this way the system initiates social interactions between the pairs of learners. In the empirical work conducted, friendship pairs were used as the basis of pairing as described in the next section.

Reflection

At the end of each stage, MIST displays a summary of the students' performance (the choices that they made during learning) and asks them to check whether they want to choose any more options or change any of the options that they have already chosen. At the beginning of every session (after the first session), students are asked to recall what activities they have already engaged in. A summary of the students' choices from all the former sessions is then presented and students are encouraged to think about their learning activities.

Apart from these, students can also review their progress during the sessions as described below. MIST allows the student to review her own progress by choosing the review progress option. At any time during learning, students can ask for a summary of their metacognitive performance. When this option is chosen, the summary is presented along with helpful questions. The system tells students about the learning activities that they chose. It then questions them to help them think whether the activities have been appropriate. Students are then advised to think about what they want to do next. If a student does not ask for a summary for a considerable period of time, the system will automatically present a summary and question the student about it. Reflection is thus combined with the more active strategy of questioning. MIST tries to encourage students to think about what they have been doing and what they want to do, thereby helping them to think about the process of learning. Apart from reviewing their own progress which can be undertaken while students are engaged in any of the stages of learning, MIST also offers the students a chance to review each other's progress. This is provided at the end of every stage before the system itself evaluates the students' performance. The system provides the student with a summary of their partner's performance and asks them to comment on it. It then provides its own evaluation of the summary. Students can thus think about the processes used by their partner. Commenting on these should help them both understand the activities better. It is, however, not possible for the system to evaluate what they say to each other, but students can compare their own evaluations with those of the system's.

EVALUATION OF MIST

Background

There have been studies demonstrating that metacognitive differences exist between learners with regard to sensitivity to text organization [37-40], and the allocation of study time and using appropriate methods [41-44]. Studies by researchers such as Chi, Bassok, Lewis, Reimann, and Glaser [45], Pirolli and Bielaczyc [46], Bielaczyc et al. [32, 47] have shown that good learners generate explanations and use self regulation skills to test their understanding. In an exploratory study conducted on secondary school children (average age 14.8 years) by Puntambekar it was found that low achievers were not very discriminating about what methods they used with reference to the task [48]. High achievers on the other hand, adapted their learning to the task in question. According to Brown, Armbruster, and Baker, important metacognitive differences exist between good and poor readers in the way they process texts [18]. In a review of the differences in text processing between good and poor readers, Brown et al., suggest that if less successful students can be made aware of the basic strategies for reading and remembering, simple rules of text construction, differing demands of the variety of tests to which their knowledge may be put, and the importance of any background knowledge that they may have, they cannot help but become more effective learners [18]. The main aim of the empirical work described here was to study the differences in the interaction with the system on the processes or learning activities reflecting metacognitive understanding of students of different abilities. Empirical studies with MIST were carried out in a secondary school with students aged fourteen to fifteen years. This age group was chosen specifically because the importance of self-study becomes more prominent in secondary schools and students have to take increasing responsibility for their learning. In many studies on metacognition, enhanced performance on a post test measure has usually been an indicator of change. Although improved performance has been recognized as the most important result of using productive study methods, it is also essential to understand the changes to the processes that students engage in, in order to help them learn effectively. One of the goals of the present study has been to look at the changes in the activities used by the learners, both during training and also in a post training task given by the experimenter. Thus the measure of the effectiveness of training was a change in the processes of learning, in addition to the performance measure. This article describes the changes in the study methods used by students of high and low abilities while interacting with computer system.

Hypotheses

Planning and monitoring have been considered to be two important aspects of metacognition [4, 14]. Our overall hypothesis was that there would be quantitative changes in the amount of time spent on planning and monitoring. In addition, there would be qualitative changes in the learning activities of students during the training sessions. These changes would be reflected in their planning behavior such as understanding the nature of the task, apportioning study time in accordance with the complexity of the task, planning study methods accordingly, and activating any prior knowledge. In addition there would be an increase in the monitoring activities such as finding main ideas, summarization, reviewing text, reviewing notes, etc.

The following specific hypotheses were put forth. As a result of training with the computer system, the students' learning behavior will show a gradual change. The changes will be more pronounced in the case of the low ability group. The specific learning activities which will be influenced are:

1. Planning. Students will engage in more planning activities as training progresses. They will understand the tasks and plan study methods appropriately. They will be able to use different skills based on the structure and content of the text and will activate any prior knowledge. However, the time spent on planning activities will start to decrease toward the end of training (see automatism).

2. Monitoring. There will be an increase in the time spent on monitoring skills such as finding main ideas, summarizing and revising, etc. Once again, the time will start to decrease toward the end of training.

3. Automatism. Although there will be an initial increase in the time spent on planning and monitoring activities of the students, these activities will become more automatic toward the end of training and less time will be spent on them (Brown's autopilot mechanism).

4. Sensitivity to the task. Students will approach different learning tasks differently. This will be reflected in their apportioning of time required for studying for different purposes, with simpler tasks being allocated less time and vice versa. The methods for tackling the different tasks will be different too, with deeper processing (complex) skills being used for the more difficult tasks. Based on evidence that good students do engage in some planning and monitoring activities and that poor students do not, it was expected that the changes in the learning activities of low ability students will undergo more changes as a result of training.

Participants

Twenty students from a local school participated in the study. All of the 238 students studying in year 9 (mean age 14.64 years), were asked who they wanted to pair with. The pairings were friendship pairings [49]. Use of pairing by friendship is based on the fact that students are more willing and motivated to cooperate when they respect their peers and really wish to help them. Pairing by cognitive criteria (e.g., ability) can sometimes be frustrating if the pairs are too heterogeneous. Since the main intention for having pairs interact with the system was to allow for maximum possible opportunities for conversation, it was decided to use friendship pairs. Out of all the pairs thus obtained, twenty-six pairs were again selected, thirteen belonging to high ability and thirteen to low ability as follows. Students' academic performance and their scores on the Learning and Study Strategy Inventory (LASSI) were used as criteria for this selection [50]. Ratings from students' teachers were obtained in order to identify high and low achievers. The ratings were on a 10-point scale, with 1 being the best and 10 being the worst. On an average, four ratings were obtained for each student. The ratings were then averaged to get an indication of the academic performance of students. Scores on LASSI were then used to split the students into the two groups. Two students were dropped because the teachers' ranks and LASSI scores did not agree and it could not be ascertained whether the students did in fact answer the test honestly. These two students got a high score on the LASSI subscales, above the 75th percentile. However, their teachers' ratings ranged form 8.3 to 9.7. Out of these students, six were dropped from the study for various reasons such as not completing LASSI and timetabling problems. There were thus twenty students participating in the study. There were ten high ability students (group HI) and ten low ability students (group LO). There was an equal number of boys and girls. All pairs turned out to be same gender pairs.

Method

The experiment was divided into three phases namely, the pre-training phase, the training phase, and the post-training phase.

The pre-training phase was the pretest to assess the baseline performance of students. Students were given two tasks—one of them was to study the text given in detail (DET), as if studying for a test. The second one was to get an overview or a summary (GIST), of a second text. Both the texts were given by the experimenter and were from their prescribed textbooks. The texts were both two pages long. The time required to study the texts, time spent on reading, taking notes, discussing the text was recorded. Students' conversations were recorded and observations were made during the testing by the experimenter.

Students interacted with the computer system during this phase. Each student spent eight hours (8 sessions of an hour each) with the system. On an average they spent about one hour with the non-interactive part (Browser) of the system at the beginning of training, learning about the different types of tasks, texts, and skills. The Browser was available for reference all through the rest of the sessions.

For the interactive part of the system, students were given a warm up session of fifteen minutes each in which they were told about the different options and their meanings. The experimenter provided help during this stage. This was to reduce any possible effects due to unfamiliarity of the interface. During the subsequent sessions, students studied from their texts. They studied from their science textbook [51]. Students completed five tasks during these sessions. The first two tasks involved studying for all details in a text (DET1 and DET2), the next two were to study to get a gist of the text (GI1 and GI2) and the last task was revision (REV).

During the sessions, students' choices were recorded by the system. In addition, the researcher was present all through the sessions to supplement the recording of the choices by observations of their activities. Their conversations were recorded as well. Students' choices relating to planning and monitoring were recorded by the system and these were analyzed for evidence of metacognitive activity. The sub-categories of planning were: specifying the purpose of studying or goal setting, apportioning study time in accordance with the task, using study methods in accordance with the task and the text, and using prereading activities such as skimming to allocate study time. The monitoring activities that are indicative of metacognitive understanding were: identifying main ideas, reviewing the text, and trying to recall the main ideas. Data relating to each of these aspects of metacognition was recorded. The data was analyzed both qualitatively and quantitatively. The time that students spent on planning, the time on monitoring, and the activities that they undertook during the five tasks were analyzed.

The post-training phase was exactly similar to the pre-training phase. Students were assessed on the same two tasks and the types of data were the same. The only difference was that the texts used were different and again were chosen by the experimenter from the books to be studied by the students in the following year. The results during the sessions in which students interacted with the computer system are described in this article.

STUDENTS' INTERACTIONS WITH MIST

Quantitative Analyses

Changes in the learning activities of students were expected during training. These changes were expected to be reflected in the planning and monitoring behaviors of students.

Time Spent on Planning

The time that students spent on each of the planning options was recorded and this was combined to find the total planning time spent on each task. The time spent was then changed into percentages to get the percentage (of total time) spent on planning during each of the tasks by the two groups of students. Figure 2 summarizes the data. It was expected that there would be an initial increase in the

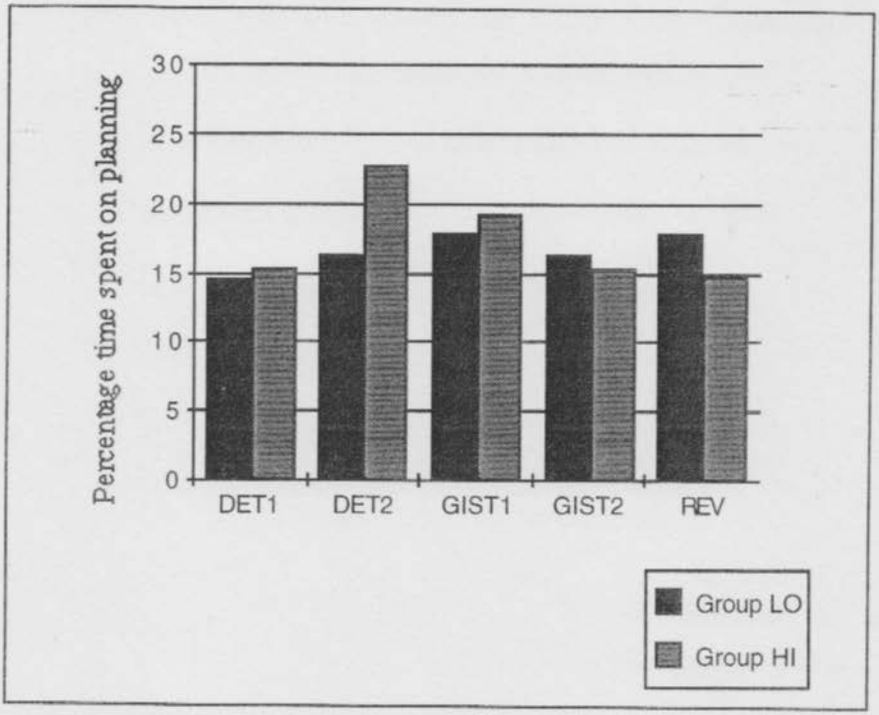

Figure 2. Percentage time spent on planning during the five tasks.

time spent on planning activities during training. Following this, there would be a decrease in the time when the choices of students became more automatic (Brown's autopilot mechanism).

Figure 2 shows that the two groups spent almost the same time on planning at the start of the training. This was contrary to the assumption that good students spend more time on planning as part of their normal studying. As was expected, there was an initial increase and a subsequent decrease in the time spent on planning related activities in the case of group HI. In the case of group LO, however, the time spent on planning increased through the tasks except for a decrease for task GI2. A t-ratio was calculated for the time spent on planning by the two groups for DET2 ($t = 5.39$, $df = 9$). It was found that students of group HI spent a significantly longer proportion of time on planning than students of group LO ($p > .01$). However, the time spent on the help cards indicates that students of group LO spent a long time trying to understand the options by using the help feature. Although this could be considered indicative of monitoring one's own understanding of the options, students of group LO clearly had some difficulties and hence asked for more help while selecting the planning options. The percentage time spent on planning for the two gist tasks was subjected to an

ANOVA test. The *F*-ratio for the main effect of tasks (GI1 and GI2) was found to be significant ($F = 8.65$, $df = 1, 36$, $MSe = 11.53$, $p < .01$). There was thus a significant decrease in the time spent on planning for task GI2. However the differences between the mean time spent on planning by the two groups was not found to be significant. But when the observations and conversation were analyzed, an interesting fact emerged. This was that although there was not a significant difference in the time spent on planning, the types of activities of the two groups differed very much. The students of Group HI spent most of their time on planning in discussing the various options such as activating prior knowledge, looking at the text and discussing the section headings, and discussing their study methods. They were setting long-term and short-term goals. However, Group LO students spent most of the time in getting help about the options and even occasionally asking the experimenter "Shall I click on this now?" But this too indicates that they were able to identify what they didn't know and were able to ask the experimenter about it. There was a rise in the time spent on planning for task DET2 in the case of both the groups. Subsequently, there was a decrease in the time for all the tasks in the case of group HI. The decrease from task GI1 to GI2 was quite sharp for group HI. As indicated above, this difference was found to be significant. A reason for this could be that the students knew what they had to do during the gist task and hence did not require much time to plan for it. An interesting fact that is seen in the graph is that for task REV, students of group HI spent almost the same time as task GI2. In the case of group LO, however, the results were quite different. The time that they spent on planning increased up to task GI1. Then there was a very slight decrease for task GI2 and once again for task REV, the planning time increased. This may have been because revision was a task that they had not undertaken before and hence they needed more time to plan what they wanted to do. Students of group HI on the other hand, could easily adapt to the new task. It seemed that students of group HI had understood the planning options and hence the time they spent on these activities decreased. If the decrease was merely a function of the familiarity of interface, then the decrease between DET2 and GI1 and between GI2 and REV would have been more drastic because the students would have chosen the options without really thinking about them. The methods of study used by students of the two groups (described in a later section) also indicated that they had thought about the options before choosing them and hence the decrease could not be attributed to a mere familiarity of interface. As was expected, students of group HI showed an increase in the planning time followed by a decrease. However, for students of group LO, the planning time increased through the sessions, except for a slight decrease for task GI2.

Time Spent on Monitoring

As with the planning time, changes in the time spent on monitoring were also expected. It was expected that the time spent on monitoring would increase and subsequently decrease as training progressed. The time spent on monitoring options such as finding main ideas, summarizing, reviewing text, and revising was recorded and this was combined to get the monitoring time for each task (Figure 3). The time spent on monitoring during the two gist tasks was much lower than the other three tasks. This was because the tasks involved finding a gist, and hence students did not choose many monitoring options during this task. Students only chose finding main ideas and not many other options such as reviewing the text, revising the text, summarizing, etc. Hence these tasks have not been considered for further analysis. There was a sharp increase in the time spent on monitoring by Group LO students as well as Group HI students during tasks DET1, DET2, and REV. Unlike the planning time where the increase was only slight for group LO, the time spent on monitoring shows a marked increase in the case of Group LO students. There was an increase in the time spent on monitoring for both the groups during task DET2 as compared to DET1. To find out whether the two groups differed significantly from each other in the time spent on monitoring for task DET2, a t-ratio was computed for the time spent on monitoring for task DET2 by good and poor students ($t = 4.08$, $df = 9$, $p = .01$). Thus

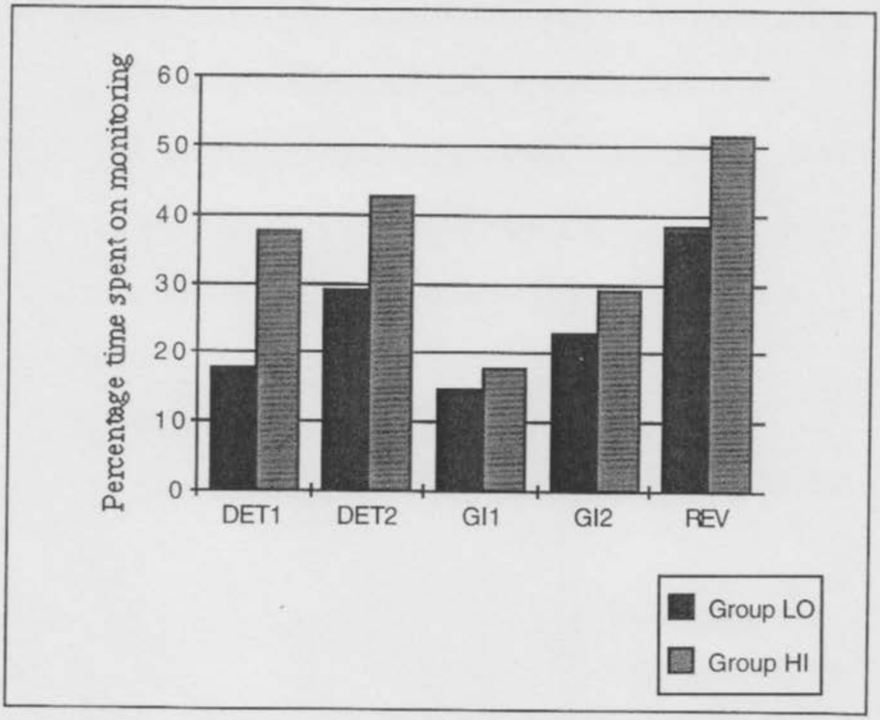

Figure 3. Percentage time spent on monitoring during the five tasks.

although there was an increase in the time spent on monitoring by both the groups on task DET2 as compared to task DET1, Group HI students engaged in significantly more monitoring related activities.

The mean time spent on monitoring by Group HI for tasks DET1 and DET2 was compared. The *t*-ratio was 2.93 which was significant at the .05 level. Thus students of group HI spent significantly more time on monitoring during the second "details" task. They also spent significantly more time on monitoring related options than students of group LO during both the details tasks. It seems that students of group HI thus benefitted more from the training. The *t*-ratio was 7.9 for the differences in means of the two groups for the revision task. This too was a significant at the .01 level. Thus the two groups differed significantly in the time spent on monitoring with the students in Group HI spending more time on it. Students in both the groups did not spend as much time on monitoring for the two gist tasks. This may have been because the students had to get only a summary of the text and they did not have to choose options such as review, recall, predict questions. Hence the monitoring time for these two tasks has not been compared with the others. Both the groups spent an increasing amount of time on monitoring related activities during the three tasks—DET1, DET2, and REV. The learning profiles recorded by the system indicate that students of both the groups not only spent more time on each of the activities of finding main ideas, summarizing, and reviewing (rereading, recalling important ideas, and rereading difficult parts) but the number and type of monitoring related activities that they chose also increased. During task DET1 only two students of group HI and none of group LO chose any of the review options. However, this number increased to nine in group HI and six in group LO for task DET2. For task REV all the students of group HI and eight students of group LO chose review options and spent an average of 69 percent of their monitoring time on these options.

Changes in Study Methods

The methods used by the students across the five tasks were compared in order to find out whether they had changed their study methods for studying for different purposes. Students of group HI altered their planned study methods according to the type of task. Only five students planned for the first task (DET1). Out of these, four of the students chose "read the text in detail," "reread if necessary," and "take notes." Only three students chose "pick out important ideas." After they had made the choice, MIST evaluated their choice options and explained to them the importance of skills such as finding main ideas. The students were also advised to go back to the browser and read about the different tasks where applicable. Subsequently, for task DET2, all the students chose planning. Out of these, five chose "skimming," none chose "read headings, summaries" nine chose "read in detail," and "pick out important ideas," and all (100%) chose "reread if necessary" and "take notes." There was a dramatic change in the methods chosen for tasks GI1 and GI2 when compared with the earlier details tasks. For task GI1, eight of students chose "skimming" and this rose to ten for task GI2. Five students chose "read summary and/or introduction" and this frequency rose to six for task GI2 (the increase was after the system explained the options in this case as well). All the students chose "pick out important ideas" for both the tasks. Three of the students still chose "read in detail" and "reread if necessary." However, this was not so for task GI2 when none of the students chose these two methods. Thus the method changed for the second gist task. The same can be seen for task "REV" when students' choice emphasized the importance of finding main ideas and taking notes, rather than reading and rereading. It may be noted that the system offered explanations about each of the options and each of the tasks. It did not instruct the students on the appropriateness of any one of the methods for a particular task because empirical data on such a task × skill interactions is not available. One of the aims of the empirical work described here was to see whether any such interactions would emerge from students' performance. In the case of group LO students, there was a change in the methods planned but the change was more gradual. Two of the students still chose to study the text in detail for GI2 and four chose to reread the text. However, the number of students choosing skimming and finding main ideas shows a steady rise. One hundred percent of the students chose skimming for task GI2. All the students chose "pick out important ideas" for tasks DET2 and GI2. The number of students choosing "take notes in detail" also decreased for task GI1 and reduced to 0 for task GI2. One interesting difference between the two groups was that 100 percent of students from Group LO chose pick out important ideas for task REV. This may have been because the students were of low ability and wanted to identify the important points when they were revising the text even though they had already done so during reading the text in detail.

Thus, as expected, students changed their study methods in accordance with the tasks as training progressed. However, the changes were gradual, even more so in the case of low ability students.

Qualitative Changes in Students' Learning

Planning

As described earlier, students of group HI spent a greater percentage of their time on the planning options than students of group LO. Students of group LO had difficulty understanding the planning options even during awareness training. Although the information presented during awareness training was quite extensive, learners of lower ability did have difficulty in understanding some of the options—especially some of the planning options as indicated by the amount of time spent on these cards. The observation also indicated that they read these options again and again. This was later reflected in their difficulty in using these options later in the training. Students from group LO did not plan appropriate study methods and chose deeper processing (as if they were reading the text in detail) options for the gist task. Even when they understood the options, they did not venture beyond the options that were explicitly mentioned on the screen. They did not choose the "other" option for any of the planning menus. Students of group HI on the other hand, used the planning options quite flexibly. When an appropriate choice was not present, they chose the "other" option and wrote down the activity they wanted to engage in. They also used the prior knowledge option in an interesting way. Whereas students of group LO answered in monosyllables such as "unfamiliar" or "very familiar," conversations of students of group HI indicated that they referred to their prior knowledge and used the option very actively. They spoke quite extensively about their experiences, especially about their experiences when the topic had been taught in the classroom. They also related the topic that they were about to study to other books that they had read. It is possible that if the system had questioned the low ability students about why a topic is familiar, it may have provoked them to speak about their prior knowledge. Another difference was that while planning how much time they would need for a task, many students of group HI split the time that they would require into its component activities such as time for skimming, for reading, and for reviewing. It was found here that many of the students of group HI tried to divide the time required into the various learning activities described in MIST.

For example, one of the students of pair 3 said, "I want to revise, so I think I will spend the first five minutes in trying to recall what I remember. Then . . . the next ten minutes, I will read the text, picking up the main ideas and . . . concentrating on what I didn't remember, then maybe I will write the main points . . . or the ones I did not remember at first—I will need about ten minutes for that. So how much is that (counting on fingers), twenty-five minutes." Toward the end of the training, students of group LO also did make near accurate estimates of the time required. However, they did not make any divisions overt. It is possible that they actually did make these divisions but did them covertly. Had the system questioned them about why they would require the time that they had planned, perhaps the divisions made by them may have become explicit. Thus on the whole it seems that MIST could have helped the low ability students better if it had been more interactive.

Monitoring

Although Group HI students spent more time on monitoring activities (Table 1), group LO students did engage in interesting monitoring activities and there were qualitative changes in the ways in which Group LO students learned the texts which indicated their changes in monitoring. An interesting example comes from two students who went on to draw a tree diagram for a text on the periodic table. After they had finished drawing, the system asked them whether they had used the right strategy and whether they wanted to use any other strategy. This was a feature that was built into the system although the system did not have any information about the text. When questioned by the system, the

Table 1. Table Showing the Proportion of Time Spent (%) on Planning and Monitoring of High (HI) and Low (LO) Ability Students

	DET1		DET2		GI1		GI2		REV	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
HI-Planning	15.1	3.2	22.6	2.4	19.2	1.9	15.3	3.9	14.8	3.7
LO-Planning	14.9	3.9	16.2	2.8	17.8	1.6	16.3	3.2	17.9	2.0
HI-Monitoring	37.5	6.9	42.6	2.9	22.7	3.4	14.9	2.7	51.6	4.5
LO-Monitoring	18.8	5.7	29.2	10.6	28.9	3.8	17.7	3.5	38.5	3.6

students (mentioned above) realized that they had not used the right strategy. One of them exclaimed, "I think we should not have made a tree. Maybe we should try a table." Subsequently, they made a two dimensional table summarizing the properties of some of the elements. Thus, although the system did not know anything about the contents of the text, it seemed to have provoked them helpfully by asking them questions. There were also differences in the types of summaries that students wrote. At first, summaries were quite scant and did not include all the main points. The system then asked them whether they had included all the main points. In subsequent sessions, when they used the same strategy again, students wrote much better summaries which were more structured. Some of the students also used more than one strategy for the same text—for example, a summary supplemented by a two dimensional table. Another noteworthy aspect was the way in which students of Group HI used the "predict questions" option in the post-reading stage. Students in group HI not only predicted a greater number of questions, but they also varied the type of questions—for example "short answers," "fill in the blanks," and "true or false." The option "predict questions" was used in another interesting way by group HI students. Three of the pairs took turns to write the questions and then answer them. For example, Student A wrote a question and asked Student B to answer it and vice versa. Although it did seem more competitive than collaborative, they used the system enjoyably to test their knowledge on the text. The ability to recall and apportion study time based on it is considered an important aspect of metacognition [44]. Although the use of questioning was intended as a means to monitor comprehension, some of the students as mentioned above used it more as a form of self and peer testing.

Interface

The process of studying from texts and not any particular text domain was the basis for the system and it aimed to encourage the students to approach the learning systematically. One of the main concerns about the design of the system was that because the system was subject-domain empty it was possible that students might actually forget to click on the options presented by the system and carry on with their studying (because the text was outside the system). However, this did not happen with any of the pairs that took part in the study. Students were quite systematic about choosing the options and then carrying out the activities that they had chosen. Students did not have difficulties in relating the options to the text that they wanted to study from. They were also quite eager to bring texts that were relevant to their current academic demands. The topics that they brought to study were being taught in the school at the time of the experiment. Many of the students chose either "Food Hygiene" or "Circulatory System" for the revision task because they had weekly tests on these topics.

Collaboration

The conversation of students was analyzed for the proportion of planning and monitoring related statements. On the whole, the planning as well as the monitoring related statements of the high ability group outnumbered those of the low ability group. This finding was in contrast to that of Bielaczyc et al. who did not find any differences in the monitoring elaborations of dyads of high and low ability [33]. However, findings of the present study indicate that it was not only the quantity of discussions but the quality varied as well. On the whole, good learners engaged in more statements relating to prior knowledge than poor learners. Thus, it seems that the system was more successful in provoking interaction in the high ability groups. The results might have been different if the low ability group had spent more time with the system. MIST was designed in such a way that students took turns to choose the options during the planning and the reading phase. During these stages, the system offered advice about who should help whom, depending on how the students performed. It was found during the interactions that students, especially low ability students, did not help each other when asked to do so (even when one of them was performing better than the other), but rather relied heavily on the system. MIST was designed with the intention of lending social support based on the cognitive and metacognitive activities of the pair. It was expected that the students who had been doing well would help the other students in the pair. However, most of the low ability students did not explain their choices to their friends even though the system instructed them to do so. One of the reasons for this may have been the presence of the experimenter in the room which made them hesitant especially about offering explanations. However, during the post reading phase when they had to discuss and build a single tree, table, etc., students were asked to work together. During this stage, one student would typically take charge of the mouse, and students chose the options after discussing with each other. They constructed the trees, maps, etc. after discussing what should be included. It was found that during this phase, students spontaneously helped each other. It may have been better if students were left to interact spontaneously (rather than taking turns) during the planning and the reading stages. But this may not work well when the pairs are based on ability and one is performing much better than the other. In such a situation, having one student in charge of the mouse may actually result in the more able students dominating the less able students.

Reflection

An issue related to the one mentioned above concerns the "peer review" option provided by the system. This was used beneficially by some of the good students and they did raise interesting points in their reviews. The most common comments by group HI students related to the time required and the methods for studying the text. Examples of such comments are "I don't think he will need 15 minutes for this task" (the task in this case was studying to get a gist); "She needn't read in detail for the revision"; "He said he was unfamiliar with the text, but we did a project on different aspects of food last year" (the topic here was pathogens and the way in which food should be stored). Although some of the good students did comment, some of them had nothing to comment on because they had chosen the same options. Some others seemed quite hesitant to comment and the presence of the experimenter may have been the reason. Thus not all the students used the peer review option well and this may have been because they were asked to review the performance of each other. Group LO students hardly commented on their friends' performance. The presence of the experimenter may have been an important factor influencing this outcome. In contrast to the peer review option, students used the review progress (self) option well and this helped them in many cases to discuss their learning activities and choose further options. Almost all the students of both the groups chose "review progress" at least once during each of the stages of planning, reading and post reading. This was in addition to the summary that the system gave them at the end of the stage.

Discussion

Time Spent on Planning and Monitoring

Drawing from the work of Brown [52], Derry and Murphy [21] describe models that attempt to logistically engineer the change from the laborious activity of the conscious level to the normal rapid automatic pilot state that distinguishes subconscious processing. According to them, subconscious or automatic processing should be reflected in smooth performance. As has been described earlier, the system was designed to impart awareness training and the interactive part of the system presented menus that acted as prompts for the students to think and choose different learning activities. Given the above features, it was hypothesized that there would be changes in the process of learning as reflected in a change in the amount of planning and monitoring, study methods used, and changes in conversation. It was expected that there would be an initial increase followed by a decrease in the planning and monitoring time (hypotheses 1 and 2). It was found that results of group HI supported the hypothesis. The time spent on planning increased and subsequently decreased for students of this group. However, this was not so in the case of group LO students and the time increased through tasks DET1, DET2, and GI1. There was a small decrease for task GI2. The planning time increased again for task REV. This may have been because the task was new, and the students of Group LO took some time to understand the ways in which they should adapt their study plans to a novel task. Students of the low ability group had difficulty in understanding the planning options. Their conversation also indicated that prior knowledge elaborations were not as many for the LO group compared to group HI and their conversation was restricted to the phrases described in the menus. To some extent, this could be rectified by making the browser more interactive. It may be more useful if the explanations offered by the browser are more dynamic such as a multimedia presentation using video or audio recordings. As has been the case in some of the strategy training studies [8, 53], modeling the desired strategies is used as one of the techniques to help students understand the correct strategies. The same may also be extended to explanation about how to apply the different strategies. It may also be useful to make the explanation about post-reading skills more active—for example presenting one text and applying different strategies to it or applying a different skill to different parts of the same text. Some students asked the experimenter in the initial training sessions for help while applying the different strategies and hence it is felt that having a more interactive interface (perhaps an audio-visual presentation) may be a more suitable improvement, especially if students wished to use the system on its own in the absence of a teacher. Another way in which students may be helped could be by asking them questions. For example, if the student chooses a particular task, let us say studying for a classroom test, the system would help the students think about what studying for a test means—What type of a test is it? How detailed should the preparation be? Similarly, if the student indicates that she has prior knowledge about a text, the system would immediately question the student about what she knows about the text and whether the knowledge will help her learn the text. The main idea behind the questioning in the planning stage would be to help the student set a clear purpose for studying so that later learning becomes easier. Considering the fact that some students found it difficult to understand the planning options, questioning them about their choices might help them clarify their objectives. Questioning will also provoke more conversation and many of the covert activities may become more explicit. The time spent on monitoring, however, increased for both the groups across the three tasks of finding details and studying for revision. Out of these, the task DET1 was the very first task and students (especially group LO) did not choose many options during this task (although they had a warm up session before this task). Hence the increase in the monitoring time for the next task seems quite understandable because during this task students did pay more attention to the menus and were actively involved in the learning. The increase in the monitoring time for the last task (REV) may have been again because the task was new and students took some time to adapt their learning activities. The results may have been different if students had been involved in more sessions. One interesting fact was that although there was an increase in planning and monitoring time for both groups, the increase was more in the case of students of high ability. This finding is somewhat similar to that of Pirolli who explains the results of a hypertext explanation environment aimed at helping students develop self explanations [54]. It was found that the low performance students "were more prone to move through the instruction (i.e., selecting the next button) than high performance subjects who tended to be more driven by their self-explanation (comprehension) strategies." The increase in the time spent on monitoring may have been because of the fact that there were only three tasks and hence it is possible that students did not get a chance to learn the skills to the extent that they resulted in smooth performance which would have reflected in a decrease in the time. It was expected that there would be differences in the time required for the tasks and also the methods used. Researchers have suggested that the effective use of one's study time is a product of students' use of learning strategies such as planning and goal setting [55]. There were significant differences in the time that students required for the details task and the gist tasks. As has been indicated earlier, students were able to estimate the time required for studying more accurately in the later sessions of the training. It was also found that students changed their study methods to suit the task. They used deeper processing methods for the tasks involving studying in detail. On the other hand, for finding a gist, they used skimming and reading headings, subheadings, and skills that enabled them to get an overview of the text. However, the changes in the study methods were gradual, even more so in the case of group LO students. The following general methods were used by students for the three tasks:

1. Details: skim text, read in detail, reread if necessary, pick out important ideas, take detailed notes
2. Gist: skim chapter, read summaries, introduction, write important points
3. Revision: Skim chapter, reread text, pick out important ideas, recall

Thus it is quite clear that students did change their study methods for different tasks. There is not much empirical evidence about the relationships between the tasks and the different skills used. This study has shown certain general trends in this direction. Although more research is necessary to firmly establish that these are the methods used by a majority of students and that they lead to success, this finding does show an important trend and provides a direction for further research into task × skills relationships.

Collaboration

It was found that students collaborated more actively during the post-reading phase when they worked together to make maps, nets, outlines on the computer.

The interactions were more spontaneous in this stage. However, during the planning and the reading stage, when they were asked to help each other depending on who was doing better and the interaction was initiated by the system, they were hesitant to offer help. A way to solve this problem may be to make the whole system depend on spontaneous interactions without offering any specific advice about who should help whom. However, this may not work very well if pairs of students are of different abilities. There is always the danger of the more able dominating the less able ones. One way to solve this problem is for the system to have some understanding of the initial ability of the students and then choose whether the students should take turns or whether they should work together. Heterogeneous pairs would thus be required to take turns until their planning and monitoring ability reaches a threshold. Thereafter, they could work together. While they take turns to choose the options, the system could ask the more able student in each pair to help the less able. Homogeneous pairs, on the other hand, could be asked to work together. At any time during the interaction students could be asked to change the mode of collaboration, i.e., taking turns or working together, depending on how they perform. It would be crucial for the system to consider the abilities of the students and relate this to their ongoing performance because students of different abilities may have different advantages of working together. For example, as found by Artzt and Armour-Thomas in their study on group problem solving, some of the high ability students wanted more input from other group members although the others were not necessarily of high ability [56]. Some other high ability students thought that they would proceed more quickly if they worked alone.

Reflection

The peer review option was used quite well by group HI students. However, the low ability students did not use this option very much. They were hesitant to comment on their friends' performance. This option could have been used more fruitfully if students were asked to review the performance of "other pairs." The system could provide them with the profiles of pairs other than themselves and it would do this after taking into account the performance of the current pair. Students in the current pair would then be asked to reflect on their own performance with reference to the other. A somewhat similar approach was proposed by Katz and Lesgold [57]. But they propose to use the system to enable students to produce a solution or to review others' solution. On the other hand, it is intended here to use the review feature to facilitate feedback and further understanding of the options. Another possibility is that the others need not necessarily be "real others." Fictitious "others" could be generated by the system specifically to provoke comments. Some of the most interesting interactions occurred during the post reading phase and it is here that the most interesting conversations took place as well. However, one limitation here was that the system did not provide any means to record the main ideas during the reading stage and students wanted to refer to these (students were asked to note the main ideas during the reading stage on paper and the experimenter retained all the notes; these were given back to the students while they did the post reading). Although they were asked to bring in their own texts, as some of the students were preparing for a test, they asked to see other pairs' summaries, questions, etc. These were stored on the computer but were not part of the system and were recalled with the help of the experimenter. The system had no means by which students could see their peers' performance. Recording the main ideas of each student and enabling them to see each others' record could be an important addition to the system. Recording main ideas early in the sessions could also be a real collaborative activity and might provoke comments as in the post-reading stage. It also seems worthwhile here to record things such as the name of the text, goals, etc. A detailed record of each learner could be kept for use by other learners and for use by the system. As has been described earlier, students of group HI used the "predict questions" option to test their own and their friend's knowledge. This seemed to be an important improvement that could be made to the system. The system could specifically ask the students to take turns to pose specific questions about the text and answer them. This option could also be extended to provide opportunities for self and other testing in the post-reading phase and help the students to relate their current state of learning to the purpose of learning that they put forth. According to Dufresne and Kobasigawa, a mature use of self-testing involves: 1) knowing what is required by the criterion task, 2) selecting the self-testing strategy that is appropriate to the learning goal, and 3) deciding whether to study longer by comparing the current state to the study goal [43]. The data about study methods that students used for each of the tasks could be used to relate the criterion task to the learning goal.

CONCLUSION

MIST is one of the first attempts at building a system totally based on the processes or the learning activities of students and not on the subject domain that they are learning. It dealt explicitly with helping students learn "how to learn." Feedback in MIST is based on the learning activities of students, i.e., on the processes that they used. The system is designed to help students develop a systematic approach to learning from texts and supports a range of planning and monitoring activities. As it is based explicitly on the activities that students may use, the system externalizes the processes that would otherwise have been covert. By providing menus based on the process, the processes that would otherwise have been tacit are made visible so that they could be open for instruction. An important aspect of MIST is that the system did not have any subject domain representation and helped students to concentrate on the process by enabling them to study from texts that were relevant to their academic goals. In an evaluation of MIST, it was found that on the whole, the group LO students had a lot of difficulty understanding the planning options. They needed more explanation in understanding the options as well as applying them to different tasks. It was therefore concluded that the interface should be more interactive and group LO students should be helped to think about the planning options, possibly with the help of questioning about each of their choices. Another aspect that was found was that the group HI students used the interface more "actively"—i.e., they used the planning options to elicit prior knowledge, they were more attentive toward features of the text such as diagrams, and they engaged in active self-testing and also tested each other. Students of group LO, on the other hand, used the options more rigidly and provided answers in monosyllables most of the time. These important differences could be used to improve instruction in metacognition by provoking more instances of active learning in lower ability students. Students of group HI discussed their learning extensively during the training. On the contrary, group LO students did not converse very much. Thus the system was more successful in provoking conversations and interactions in the high ability students than in the low ability ones. This aspect is important to bear in mind while designing interventions. It may be that if the low ability students had more time with the system they would have been more active learners. MIST used collaboration and reflection to facilitate learning. It was found that group HI pairs engaged in more conversation and used more self and other testing. Group LO pairs, on the other hand, did not comment much on the performance of their peers. These findings could be used to build systems that help in collaboration by providing explicit instructions about how the students should interact with each other. Similarly, more opportunities for peer review should be provided. Based on these findings MIST could be improved so that it will be beneficial to low ability students as well.

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REFERENCES

1. P. Dillenbourg, The Computer as a Constructorium: Tools for Observing One's Own Learning, in *Knowledge Negotiation*, R. Moyse and M. T. Elsom-Cook (eds.), Academic Press, London, 1992.
2. S. J. Derry and L. W. Hawkes, Local Cognitive Modelling of Problem Solving Behavior: An Application of Fuzzy Theory, in *Computers as Cognitive Tools*, S. P. Lajoie and S. J. Derry (eds.), Erlbaum, Hillsdale, New Jersey, 1993.
3. S. Derry, K. Tookey, and B. Roth, The Effect of Collaborative Interaction and Computer Tool Use on the Problem-Solving Processes of Lower Ability Students, *AERA Presentation*, Atlanta, Georgia, 1993.
4. S. Derry, K. Tookey, and A. Chiffy, *A Microanalysis of Pair Problem Solving with and without a Computer Tool*, paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, Louisiana, 1994.

5. K. R. Tookey and S. Derry, *Arithmetic Schema and Strategy Instruction: A Study of Two Problem Solving Training Approaches*, presented at the annual meeting of the American Educational Research Association, San Francisco, California, 1996.
6. P. H. Winne, *The Study System*, personal communication, 1991.
7. P. H. Winne, Inherent Details in Self-Regulated Learning, *Educational Psychologist, 30*, pp. 173-187, 1995.
8. A. L. Browne and A. S. Palincsar, Reciprocal Teaching of Comprehension Strategies: A Natural History of One Program for Enhancing Learning, in *Intelligence and Exceptionality: New Directions for Theory, Assessment, and Instructional Practice*, J. D. Day and J. G. Borkowski (eds.), Ablex, Norwood, New Jersey, 1978.
9. T. Chan and A. Baskin, *Studying with the Prince*, in proceedings of the conference on Intelligent Tutoring Systems, Montreal, Canada, 1988.
10. P. Dillenbourg, *Human-Computer Collaborative Learning*, unpublished doctoral dissertation, University of Lancaster, 1991.
11. A. Collins and J. Brown, The Computer as a Tool for Learning through Reflection, in *Learning Issues for Intelligent Tutoring Systems*, H. Mandl and A. Lesgold (eds.), Springer-Verlag, New York, 1988.
12. A. L. Brown, Metacognition: The Development of Selective Attention Strategies for Learning from Texts, in *Directions in Reading: Research and Instruction*, M. Kamil (ed.), The National Reading Conference, Washington, D.C., 1981.
13. J. Flavell, Metacognitive Aspects of Problem Solving, in *The Nature of Intelligence*, L. Resnick (ed.), Erlbaum, Hillsdale, New Jersey, 1976.
14. A. L. Brown, Motivation to Learn and Understand: On Taking Charge of One's Own Learning, *Cognition and Instruction, 5*:4, pp. 311-322, 1988.
15. A. L. Brown, The Advancement of Learning, *Educational Researcher, 23*:8, pp. 4-12, 1994.
16. P. M. Fischer and H. Mandl. Learner, Text Variables, and the Control of Text Comprehension and Recall, in *Learning and Comprehension of Texts*, H. Mandl, N. Stein, and T. Trabasso (eds.), Erlbaum, Hillsdale, New Jersey, 1984.
17. A. L. Brown, J. Bransford, R. Ferrera, and J. Campione, Learning, Remembering and Understanding, in *Handbook of Child Psychology* (4th Edition), Cognitive Development, Vol. 3, J. H. Flavell and E. M. Markman (eds.), Wiley, New York, 1983.
18. A. L. Brown, B. B. Armbruster, and L. Baker, The Role of Metacognition in Reading and Studying, in *Reading Comprehension: From Research to Practice*, J. Orasanu (ed.), Erlbaum, Hillsdale, New Jersey, 1985.
19. A. L. Brown, Knowing When, Where and How to Remember: A Problem of Metacognition, in *Advances in Instructional Psychology*, R. Glaser (ed.), Erlbaum, Hillsdale, New Jersey, 1978.
20. J. Gavelek and T. Raphael, Metacognition, Cognition and the Role of Questioning Activities, in *Metacognition, Cognition and Human Performance, Vol. 2, Instructional Practices*, D. Forrest-Pressley, G. M. Kinnon, and T. Waller (eds.), Academic Press, New York, 1985.
21. S. Derry and D. Murphy, Designing Systems that Train Learning Ability: From Theory to Practice, *Review of Educational Research, 56*:1, pp. 1-39, 1986.

22. P. Bell and E. A. Davis, *Designing an Activity in the Knowledge Integration Environment*, paper presented at AERA, New York, 1996.
23. G. G. Duffy and L. R. Roehler, Teaching Reading Skills as Strategies, *Reading Teacher, 41*, pp. 414-418, 1987.
24. R. Garner, *Metacognition and Reading Comprehension,* Ablex, Norwood, New Jersey, 1987.
25. S. Symons, B. L. Snyder, T. Cariglia-Bull, and M. Pressley, Why be Optimistic about Cognitive Strategy Instruction? in *Cognitive Strategy Research: From Basic Research to Educational Applications*, C. B. McCormick, G. E. Miller, and M. Pressley (eds.), Springer-Verlag, New York, 1989.
26. B. Taylor and R. Beach, The Effects of Text Structure Instruction on Middle Grade Students' Comprehension and Production of Expository Text, *Reading Research Quarterly, 19*, pp. 134-146, 1984.
27. B. Jones, M. Amiran, and M. Katims, Teaching Cognitive Strategies and Text Structures within Language Arts Programs, in *Thinking and Learning Skills, Vol. 1, Relating Instruction to Research*, J. Segal, S. Chipman, and R. Glaser (eds.), Erlbaum, Hillsdale, New Jersey, 1985.
28. D. Dansereau, Learning Strategy Research, in *Thinking and Learning Skills, Volume 1, Relating Instruction to Research*, J. W. Segal, S. F. Chipman, and R. Glaser (eds.), Erlbaum, Hillsdale, New Jersey, 1985.
29. T. D. Koschman, A. C. Myers, P. J. Feltovich, and H. S. Barrows, Using Technology to Assist in Realizing Effective Learning and Instruction: A Principled Approach to the Use of Computers in Collaborative Learning, *The Journal of the Learning Sciences, 3*:3, pp. 227-264, 1994.
30. M. Scardamalia and C. Bereiter, Computer Support for Knowledge Building Communities, *The Journal of the Learning Sciences, 3*:3, pp. 265-284, 1994.
31. R. Pea, Seeing What We Build Together: Distributed Multimedia Learning Environments for Transformative Communications, *The Journal of the Learning Sciences, 3*:3, pp. 285-300, 1994.
32. K. Bielaczyc, P. Pirolli, and A. L. Brown, *Strategy Training in Self-Explanation and Self Regulation Strategies for Learning Computer Programming*, Report No. CSM-5, University of California at Berkeley, 1994.
33. C. O'Malley, Designing Computer Systems to Support Peer Learning, *European Journal of Psychology of Education, 7*:4, pp. 339-352, 1992.
34. S. D. Teasley and J. Roschelle, Constructing a Joint Problem Space: The Computer as a Tool for Sharing Knowledge, in *Computers as Cognitive Tools*, S. P. Lajoie and S. J. Derry (eds.), Erlbaum, Hillsdale, New Jersey, 1993.
35. R. E. Slavin, *Cooperative Learning: Theory Research and Practice,* Prentice-Hall, Englewood Cliffs, New Jersey, 1991.
36. M. Guzdial, M. Konneman, C. Walton, L. Hohmann, and E. Soloway, Layering Scaffolding and CAD on an Integrated Workbench: An Effective Design Approach for Project-Based Learning Support, *Interactive Learning Environments*, in press.
37. F. W. Danner, Children's Understanding of Intersentence Organization in the Recall of Short Descriptive Passages, *Journal of Educational Psychology, 68*, pp. 174-183, 1976.

38. K. M. Fischer and J. Faletti, *Promoting Metacognition about Knowledge Organization Skills in Biology,* paper presented in the symposium on Metacognition & Conceptual Change at the annual meeting of the American Educational Research Association, Atlanta, 1993.
39. A. L. Brown and S. S. Smiley, Rating the Importance of Structural Units of Prose Passages: A Problem of Metacognitive Development, *Child Development, 48,* pp. 1-8, 1977.
40. S. R. Yussen, S. R. Matthews, R. R. Buss, and P. T. Kane, Developmental Changes in Judging Important and Critical Elements of Stories, *Developmental Psychology, 16,* pp. 213-217, 1980.
41. H. K. Smith, The Responses of Good and Poor Readers When Asked to Read for Different Purposes, *Reading Research Quarterly, 3,* pp. 53-84, 1967.
42. A. Kobasigawa, C. C. Ransom, and C. J. Holland, Children's Knowledge about Skimming, *Alberta Journal of Educational Research, 26,* pp. 169-182, 1980.
43. A. Dufresne and A. Kobasigawa, Children's Utilization of Study Time: Differential and Sufficient Aspects, in *Cognitive Strategy Research: From Basic Research to Educational Applications,* C. B. McCormick, G. E. Miller, and M. Pressley (eds.), Springer-Verlag, New York, 1989.
44. A. Kobasigawa, M. A. Choinard, and A. Dufresne, Characteristics of Study Notes Prepared by Elementary School Children: Relevancy and Efficiency, *Alberta Journal of Educational Research, 34,* pp. 18-29, 1988.
45. M. T. H. Chi, M. Bassok, M. W. Lewis, P. Reimann, and R. Glaser, Self-Explanations: How Students Study and Use Examples in Learning to Solve Problems, *Cognitive Science, 13,* pp. 145-182, 1989.
46. P. Pirolli and K. Bielaczyc, Empirical Analysis of Self Explanation and Transfer in Learning to Program, in *Proceedings of the 11th Annual Conference of the Cognitive Science Society,* Erlbaum, Hillsdale, New Jersey, 1989.
47. K. Bielaczyc, P. Pirolli, and A. L. Brown, *Training in Self-Explanation and Self-Regulation Strategies: Investigating the Effects of Knowledge Acquisition Activities on Problem Solving,* Report No. CSM-7, University of California at Berkeley, 1993.
48. S. Puntambekar, Helping Students Learn "How to Learn" from Texts: Towards an ITS for Developing Metacognition, *Instructional Science, 23,* pp. 163-182, 1995.
49. D. Whitelock, J. Taylor, T. O'Shea, E. Scanlon, P. Clark, and C. O'Malley, *What Do You Say after You Have Said Hello? Dialogue Analysis of Conflict and Cooperation in a Computer Supported Collaborative Learning Environment,* paper presented at the 11th international PEG conference, 2nd-4th July 1993, Edinburgh, 1993.
50. C. E. Weinstein, S. A. Zimmerman, and D. R. Palmer, Assessing Learning Strategies: The Design and Development of the LASSI, in *Learning and Study Strategies: Issues in Assessment, Instruction, and Evaluation,* C. E. Weinstein, E. T. Goetz, and P. A. Alexander (eds.), Academic Press, New York, 1988.
51. G. Jones, M. Jones, and P. Marchington, *Balanced Science,* Vols. 1 and 2, Cambridge Press, 1990.
52. A. L. Brown, Metacognitive Development and Reading, in *Theoretical Issues in Reading Comprehension,* R. Spiro, B. Bruce, and W. Brewer (eds.), Erlbaum, Hillsdale, New Jersey, 1980.

53. B. F. Jones, *Integrating Learning Strategies and Text Research to Teach Higher Order Thinking Skills in Schools*, paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada, April 1983.
54. P. Pirolli, Towards a Unified Model of Learning to Program, in *Cognitive Models and Intelligent Environments for Learning Programming*, E. Lemut, B. du Boulay, and G. Dettori (eds.), NATO ASI Series, Springer-Verlag, Berlin, 1992.
55. B. J. Zimmerman, D. Greenberg, and C. E. Weinstein, Self-Regulating Academic Study Time: A Strategy Approach, in *Self-Regulation of Learning and Instruction: Issues and Educational Applications*, D. H. Schunk and B. J. Zimmerman (eds.), Erlbaum, Hillsdale, New Jersey, 1994.
56. A. F. Artzt, E. Armour-Thomas, Development of a Cognitive-Metacognitive Framework for Protocol Analysis of Mathematical Problems Solving in Small Groups, *Cognition and Instruction, 9*:2, pp. 137-175, 1992.
57. S. Katz and A. Lesgold, The Role of the Tutor in Computer-Based Collaborative Learning Situations, in *Computers as Cognitive Tools*, S. P. Lajoie and S. J. Derry (eds.), Erlbaum, Hillsdale, New Jersey, 1993.

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