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AUTHOR	Davis, Elizabeth A.
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ABSTRACT

This paper presents research on middle school students working on large science projects in the Knowledge Integration Environment. The objective was to develop an exemplary program of metacognitive prompts to encourage principled knowledge integration by students working on large science projects. The research indicates that metacognitive scaffolding provided through prompts improves the quality and quantity of students' work. The two studies discussed in this paper investigate students' use of two types of metacognitive prompts: activity-focused prompts and self-monitoring prompts. Activity prompts walk students through the important steps in the activities comprising a large science project while self-monitoring prompts encourage planning for and reflection on those activities. Results indicate that metacognitive prompts have both strengths and weaknesses. Activity prompts help students finish activities but do not necessarily help the students develop an integrated understanding. Self-monitoring prompts encourage students to plan their activities, remind students to reflect on their own understanding, and improve students' likelihood of explaining and justifying the decisions they make. Possible cognitive mechanisms are proposed. Contains 16 references. Sample activities are appended. (Author/JRH)

Metacognitive Scaffolding to Foster Scientific Explanations

Elizabeth A. Davis

Education in Mathematics, Science, and Technology
University of California at Berkeley

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Abstract

This paper presents research on middle school students working on large science projects in the Knowledge Integration Environment. The research indicates that metacognitive scaffolding provided through prompts improves the quality and quantity of students' work. The two studies discussed here investigate students' use of two types of metacognitive prompts: activity-focused prompts and self-monitoring prompts. Activity prompts walk students through the important steps in the activities comprising a large science project (such as providing justifications or explaining decisions), while self-monitoring prompts encourage planning for and reflection on those activities. Activity prompts are found to help students complete all the pieces of a project, but self-monitoring prompts encourage students to demonstrate an integrated understanding of the relevant science. Possible cognitive mechanisms are proposed.

Introduction

The objective of this research is to develop an exemplary program of metacognitive prompts to encourage principled knowledge integration by students working on large science projects. Through this research, I address two questions. First, what effect do "self-monitoring" and "activity-focused" metacognitive prompts have on middle school students' ability and propensity to develop an integrated understanding of science topics? Second, what is the explanation for the difference in effects of the two types?

Two studies address these questions. The first section of this paper presents a description of the relevant aspects of the Knowledge Integration Environment, the Computer as Learning Partner classroom, and the theoretical framework on which the research is based. The second section of the paper presents the methods used in the two studies, and the third section summarizes the findings. In the final section, I discuss the contributions of the research to educational practice and theory.

Context for the Research

The Knowledge Integration Environment (KIE) implements projects centered around understanding scientific evidence on the World-Wide-Web. KIE blends custom and commercially-available software. The KIE software is used by students participating in curriculum units developed by the KIE research group and others. Those units, called "projects", are designed to encourage students to attain a deep understanding of science concepts rather than to collect scientific facts, and have been used successfully as a venue in which students can apply the science principles they have been learning in class. KIE projects fall in three major categories: critiques, debates, and design projects. Critique projects foster the development of a critical eye when using evidence and evaluating arguments. Debates help students see that multiple sides may exist to arguments and that evidence should be used effectively to improve those arguments. Design projects engage students in an application of their knowledge.

Among other sites, KIE is being implemented in the Computer as Learning Partner (CLP) classroom. CLP provides a one-semester curriculum introducing the physical science topics of thermodynamics, light, and sound to eighth-graders. In the curriculum, which is laboratory-based, the computer is used as a tool to collect and graph real-time data, perform simulations of experiments that consume too much time to do during a class period, and help students track their progress in moving through the sections of the lab. The KIE software and curricula have developed directly out of CLP's decade of research on designing curricula and technology for middle school science teaching and learning. The KIE projects discussed here have been designed to complement the CLP curriculum.

KIE and CLP are guided by a framework called "scaffolded knowledge integration." The scaffolded knowledge integration instructional framework has four elements (Linn, 1995). First, we make thinking visible to students by illustrating diverse forms of expertise and reasoning about scientific phenomena. Second, we identify accessible models for scientific phenomena to help students connect new information to existing knowledge and to problems that are both familiar and relevant. Third, we provide social supports for the students as they learn. Finally, we engage students as lifelong and autonomous learners—as both investigators and critics—so they can recognize the various sides of arguments, identify weaknesses in their own and others' arguments, and identify ways to strengthen those arguments.

Prompts represent one aspect of the scaffolding in KIE. The research discussed in this paper focuses in particular on "activity prompts" and "self-monitoring prompts", which provide metacognitive opportunities for students. Activity prompts serve as memory support, while self-monitoring prompts promote reflection. The following section will discuss the rationale for such prompts.

Reflection through metacognitive prompts

This research on prompts has grown out the extensive history of the idea of "reflection." Today's educational researchers generally accept the need for reflection in students' learning, although it is not always incorporated into instructional practice. Reflection provides one method for fostering conceptual change and knowledge integration by helping students to differentiate among ideas and make connections between them. Reflection can be facilitated through many different mechanisms and can focus on different aspects of the learning process. Here, the investigation is restricted to prompting as a mechanism for reflection. In particular, I investigate aspects of students' planning and monitoring of their learning activities.

One way reflection has been encouraged in the classroom has been through teacher questioning. In recent decades, though, there has been increased interest in the *types* of questions being asked and answered. In the 1950s, the inquiry teaching method was popular. At that time, teachers were taught that they must ask students questions and get them to be active participants in their own education. Bloom's taxonomy characterized the nature of questions, and determined, distressingly, that teachers asked primarily fact-oriented questions. As a result, teachers were then encouraged not only to ask more questions, but to make those questions of a higher order than they had previously been, since asking higher order questions is thought to get students to continue the process of reflection on their own. Programmed instruction provided one attempt to have students answer these important questions.

Years later, collaborative learning has provided a new way of addressing these issues. Recent research seeks to foster the development in students of self-sustaining thinking skills through the use of these higher order questions. For example, in reciprocal teaching, used most often in reading classes, students prompt each other to explain using a set of general questions that can be asked about any kind of paragraph (Brown & Palincsar, 1989). Situated cognition and cognitive apprenticeship emphasize the importance of tying the questions being asked to the subject matter at hand (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989).

Many researchers have investigated the importance of explanations in understanding. Students who self-explain demonstrate superior problem solving ability, and research indicates that eliciting self-explanations leads to improved understanding of texts (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, deLeeuw, Chiu, & LaVancher, 1994; see also Webb, 1983). Bielaczyc (Bielaczyc, Pirolli, & Brown, 1995) found that students can be trained to give self-explanations, and that this training also facilitates the end result of improved understanding of the procedural domains in which the research has been performed. Bielaczyc's study provided the first evidence of the existence of a causal (rather than correlative) relationship between giving self-explanations and improved ability, in this case in computer programming.

We have reason to believe that giving explanations benefits students' deep understanding, as well. Linn (1995) notes that knowledge integration in science comes about when students link and connect ideas, leading them to develop a cohesive view of science and to be able to apply their knowledge of science to new, personally-relevant problems. KIE projects are designed to facilitate development of this type of deep understanding, and prompts serve as part of that facilitation. The explanations investigated here, then, will be written ones made in response to prompts. KIE's prompts are similar to those used in CSILE (Scardamalia & Bereiter, 1991). From a Vygotskian perspective (Vygotsky, 1934/1962), prompts help students move into their zone of proximal development: prompts provide an opportunity for students to make self-explanations, and give students a better understanding of the kinds of questions they should be addressing. Scardamalia and Bereiter (1991; Bereiter & Scardamalia, 1987) have found that, with proper external supports to focus their attention on the salient planning and justification issues of writing, middle school students can "transform" their knowledge into more than a series of facts or statements rather than relying on a knowledge telling strategy for writing. They also find that prompted students show increased metacognitive activity.

The prompts in KIE focusing on explanations are activity-specific; that is, they are developed with a particular activity, such as critiquing evidence, in mind.

Research indicates that this specificity is important. Linn and Clancy (1992) have found that students are most successful at learning when they are working within a concrete context rather than at an abstract level. Davis (1995) found that students benefit from contextualized prompts that help them clarify and focus their thinking. Linn and Songer (1991) found that prompting students to make predictions and observations in labs encourages integration of ideas. And, in reciprocal teaching, students essentially internalize an appropriate program of prompts for a particular activity—for example, reading a passage (Brown & Palincsar, 1989). All of these research efforts point to the importance of providing contextualized scaffolding rather than asking abstract questions. Similarly, *activity prompts* in KIE are designed to help students to identify appropriate, detailed considerations as they work on individual activities within the context of a large project. This guidance helps students to convince others (e.g., their peers and teachers) that their work is valid, by helping them to work through aspects of the expert thinking process. An activity prompt might, for example, provide students with the opportunity to justify their decisions or write scientific explanations of those decisions. For some students, activity prompts may serve simply as reminders. For others, they may act as pointers to new considerations.

Prompts to encourage self-monitoring are also beneficial. White and Frederiksen (1995) have shown great success with planning and reflection prompts with self-assessment activities in their mechanics curriculum for junior high students. Students who routinely answered such prompts developed greater understanding of the subject matter. Some of the reciprocal teaching prompts, for example those that encourage students to assess their own understanding of the material, also address monitoring issues. Likewise, KIE's *self-monitoring prompts* are planning and reflection prompts designed to help students map out their strategies for an activity, and then reflect back on that activity and identify their work's strengths and weaknesses. Self-monitoring prompts encourage students to think carefully about their own activities, encouraging planning and reflection, rather than focusing only on the short-term, smaller goals. The prompts help students think about large problems in ways an expert might consider appropriate: considering the overarching goal or goals, identifying ways in which to accomplish those goals, evaluating one's progress at regular intervals, and developing strategies for improving one's understanding of the problem at hand.

Thus, properly constructed programs of prompts can serve two roles in achieving the overarching goal of knowledge integration: they provide the impetus for explanation (and thus facilitate the process of knowledge integration in the particular context in which they are given), and they encourage reflection at a level than students do not generally consider (and thus help students develop the thinking strategies they need for effective knowledge integration and lifelong learning).

Methods

This research undertakes to measure the relative success of different types of prompts and focuses on developing prompts that are useful to different kinds of learners. Two studies have been conducted already. (A third is currently underway.) The methods used for the two studies will be discussed here, after a discussion of the development of the prompts in KIE.

Design of Prompting

Scaffolding is present in various forms throughout the KIE software and curriculum. Scaffolding is also called "guidance", a more student-friendly term. (Figure 1 provides a diagrammatic representation of the scaffolding explicitly provided by KIE.) The word processing files with which the students work provide explicit, interactive, bi-directional guidance, called "prompts". Prompts appear in the form of sentence-starters and students write responses that complete the sentences. The software also provides uni-directional guidance, in the form of a checklist and hints from the software's cognitive guidance system, called "Mildred." Students do not make written responses to this type of scaffolding. The checklist helps students keep track of what they are doing, and the hints help them with both logistical and conceptual issues.

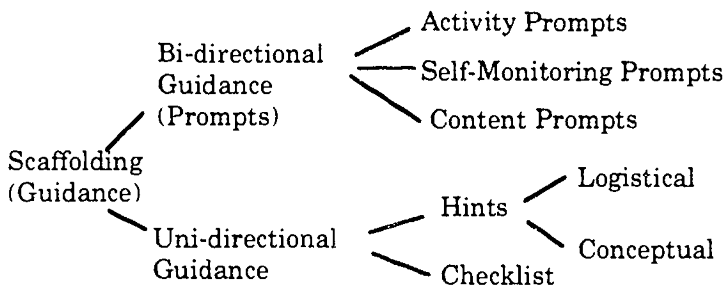

Figure 1: Scaffolding in KIE

The guidance provided by KIE builds on our experiences with CLP. For example, sentence-starter prompts have been used successfully in the CLP laboratory software. With the help of these prompts, students learn to make predictions, analyze results, and draw conclusions in their lab "reports." The CLP software also provides a checklist of activities. The checklist significantly reduces the amount of time the teacher spends answering procedural questions (e.g., "What do we do next?") and frees up time for conceptual questions (e.g., "Why would the temperature drop along a curve like that?"). The CLP software also provides logistical help with using the software, and provides cognitive guidance to help students think about each activity.

Procedural, logistical, and conceptual guidance are available, then, in both the CLP and KIE software. Although the presentation is different, the intent is largely the same. The primary difference in the two approaches is that KIE, because of its potential use by students working without close contact with a teacher, has a greater emphasis on conceptual guidance in the form of both hints and prompts. Activity prompts and self-monitoring prompts are two types of that conceptual guidance from which students benefit.

Methods for Study 1

The first study of the metacognitive prompts was performed in the context of the design project called "Aliens On Tour." The goal of the study was to assess the effect of self-monitoring prompts, which were additional requirements for half of the students. For the "Aliens" project, students were asked to design houses and clothing for three sets of cold-blooded aliens with different climate requirements. The evidence the students reviewed included data on insulation properties of different materials, advertisements for clothing items or "coolers," and other relevant information. The students were nearing completion of the semester-long CLP course focusing on heat and light energy, and were expected to bring their knowledge of these areas into their designs, as well. Students worked in pairs or occasionally triads, and they created 65 house and clothing designs altogether.

The students reviewed the evidence, then created their designs consisting of text and, in some cases, graphics. KIE provided general instructions as to what information should be included in the designs, as well as an admonition to back up all decisions with scientific evidence. As they completed each design, students saw an activity prompt asking why their design would work well for the different types of aliens. This prompt, along with the general instructions given, helped students think about the justification necessary to demonstrate to others the quality of their design, a process quite familiar to expert scientists. The activity prompt stated, "Our design will work well because...."

In addition, half of the students (three class periods) received seven specific self-monitoring prompts at the beginning and end of each activity of the project (in other words, before and after they reviewed the evidence, and before and after each of the two designs). The "plan ahead" prompts asked them to write about what they needed to think about for the activity. A plan ahead prompt used in the design activity was, "In thinking about doing our design, we need to think about...." The "look back" prompts asked them to reflect on what aspects of the activity were still confusing to them, or how their designs could be better. A look back prompt used was, "Our design could be better if we...." Appendix A provides a subset of the documents with which students in this condition worked.

Thus, in "Aliens", two conditions were investigated: one group received *activity prompts*, and the other received *self-monitoring prompts* in addition to the activity prompts. Table 1 summarizes the conditions in this study and in Study 2.

Period	Study 1 (Aliens, S95)	Study 2 (ATN, F95)
1	AP	AP
2	teacher prep.	AP
3	SMP + AP	BP (Control)
4	SMP + AP	SMP
5	SMP + AP	teacher prep.
6	AP	teacher prep.
7	AP	SMP

Table 1: Studies 1 and 2*

* AP = Activity Prompt, SMP = Self-Monitoring Prompt, BP = Beliefs Prompt; teacher prep. = no class meeting

Students' specific responses to the two types of prompts were coded according to their content. The coding scheme for the self-monitoring prompts noted the aspects on which the students chose to focus (for example, a goal restatement or a science question). For the activity prompts, the coding scheme identified whether the responses contained scientific content or not. Students' final designs were also coded. The salient aspects of the project coding were: level of explanation (scientific, explanatory, or descriptive), number of scientific principles used, and overall solution quality. All these results were incorporated into chi-square tests to compare the two conditions.

Methods for Study 2

Study 2 was undertaken for three purposes: (1) to test similar (but refined) prompts in a different project, with the intent of comparing students' responses in different contexts; (2) to investigate separately the activity and self-monitoring prompts to identify their individual strengths and weaknesses; and (3) to create a program of each type of prompts that would allow students in each condition to spend comparable amounts of time on the actual project work itself.

Studies 1 and 2 took place in sequential semesters. Study 2 was informed by the results of the first. In the critique project called "All The News", students critiqued evidence cited by a news article about energy conversion. The project involved (a) reading the article to be critiqued and looking at its concomitant evidence (about heat flow and energy conversion), (b) critiquing the evidence and the claims being made, and (c) writing a letter to the imaginary "editor" explaining the critique made and giving guidelines for future use of evidence.

"All The News", unlike "Aliens", took place early in the semester. Again, students worked in pairs or triads on the project.

In Study 2, the activity prompts underwent significant refinement. The new activity prompts grew out of those in "Aliens", but included not just prompts for justification but for all the steps necessary to do a good job on the project. For example, students were prompted for the guidelines for using evidence with the prompt, "When you think about evidence, in general you should make sure to consider...." Appendix B provides some of the documents with which students in this condition worked.

The self-monitoring prompts were also refined in "All The News." The basic refinement made to the self-monitoring prompts was to include thinking types before each prompt, similar in nature to those used in the CSILE program (Scardamalia & Bereiter, 1991), to cue the students as to what kinds of planning and reflection are important. Examples of thinking types include "Thinking Ahead", "What to Include", "Checking Our Understanding", and "How We Spent Our Time." One self-monitoring prompt for planning the "letter to the editor" was, "Specific things we need to think about as we write our letter include..."; one reflection self-monitoring prompt from that activity was "In looking back at what the editor wanted, we think she will like our letter because...." Appendix C provides a subset of the documents with which students in this condition worked.

A set of "belief prompts" were used in the control condition to ensure that all students spent similar amounts on the project itself. These prompts asked students about their beliefs about using and critiquing evidence. An example prompt is, "If two people believe two different claims, it means...." Belief prompts acted as time fillers and were unlikely to influence students' learning.

In Study 2, then, three conditions were investigated: two periods received activity prompts (the AP condition), two periods received self-monitoring prompts (the SMP condition), and one period received beliefs prompts (the BP, or control, condition). See Table 1 for a summary of the conditions.

Similar coding schemes were used for Study 2 as for Study 1. The self-monitoring prompts coding was refined to allow identification of major themes across multiple prompt responses. These qualitative themes, though , provide insight into what students are thinking about as they work with self-monitoring prompts. The major refinement to the first study's analysis was to the project coding, which for Study 2 focused on (a) principled knowledge integration as demonstrated by the "cites" students gave for their explanations, (b) the level of explanations given, and (c) the characteristics of the guidelines they provided. The analysis made use of chi-square tests and Fisher Exact tests.

Results: Measuring the Success of Prompts

To assess the success of the metacognitive prompts, we can investigate (1) the degree to which the students complete the pieces of the project required, and (2) the quality of those pieces. The following sections discuss the findings regarding these measures.

Prompting and Project Completion

As anticipated, students in activity prompt (AP) condition in Study 2 were significantly more likely to complete all pieces of the project. In the "All The News" project, approximately 78% of the AP group completed all pieces of the project, as compared to 32% of the self-monitoring prompt (SMP) group and 42% of the control group. A Fisher's Exact test found that the AP group was significantly more likely than the SMP group ($p < 0.002$) and than the control group ($p < 0.04$) to complete all the pieces of the project.

To provide the most direct scaffolding, the AP group was explicitly prompted with sentence-starters for each piece whereas the other groups received only the section headings and some prose discussing each piece. The headings and prose were present for each of the three groups. Although the existence of a difference in completion rates was not surprising, the degree to which the conditions performed differently was unexpected.

In this critique project, activity prompts provide students with tangible reminders to discuss the important aspects of the project. In this way, they help to reduce students' cognitive load. These prompts also present opportunities for students to identify pieces of evidence or aspects of the article that require improvement and provide reasons behind their thinking. They guide the inquiry process and thus help students to walk through the activities step-by-step.

Prompting and Project Quality

Although the activity prompts proved more successful at encouraging students to complete all the pieces of the project, the activity prompts did not facilitate improved quality. Identifying a single indicator of quality across projects is inappropriate because the cognitive goals of the two types of projects differ. Based on measures appropriate for each project, results indicate that students in the self-monitoring conditions tended to create higher-quality projects.

Justification

Not surprisingly, the activity prompts in the "Aliens" project were more successful at directly eliciting scientific thought than were the more general self-monitoring prompts. However, indirect results of the self-monitoring prompts are apparent. (See Table 2 for the results of the chi-square tests for Study 1.) The students in the condition with self-monitoring prompts were less likely to give purely descriptive explanations than were those students in the other group, and were significantly more likely to use at least one scientific principle in their designs ($\chi^2 = 8.92$, $p < 0.05$, $df = 2$). There was no difference in the overall quality of the two groups' projects, a phenomenon that is particularly interesting given that these prompts were essentially additional cognitive requirements for the students who completed them; the classes who received only activity prompts had, in effect, more time for their reports.

	Activity Prompt Group (N = 33)	Self-Monitoring + Activity Prompt Group (N = 32)
Level of Explanation	*(not significant)*	
Scientific	36.36%	25.00%
Explanatory	33.33%	59.38%
Descriptive	30.30%	15.62%
Number of Principles	*(p < 0.05)*	
More than one	51.52%	37.50%
One	27.27%	59.38%
Zero	21.21%	3.12%
Activity Prompt	*(not significant)*	
Scientific Content	33.33%	46.88%
No Scientific Content	67.67%	53.12%

Table 2: Chi-Square Results for Study 1

The self-monitoring prompts did not appear to move students to the highest possible levels of performance in that they did not elicit explanations involving multiple principles. Instead, the presence of the prompts affected whether students gave any explanation or justification.

It appears that there was also an interaction between the self-monitoring prompts and the activity prompts, which simply asked students to write why their design would work well. Students who received the self-monitoring prompts were more likely to include scientific content in the end-of-design activity prompt. Of the students in the self-monitoring prompt condition, 47% included scientific content in the activity prompt, as compared to only 33% of the students in the activity prompt group. (See Table 2.) Though this difference is not significant, it lends further credence to the hypothesis that students who created an explicit plan for their activities and reflected on their work were more aware of the need to provide scientific justification for their decisions. It also suggests that a mix of prompts may prove most beneficial for some students' understanding. Helping students to express their scientific ideas facilitates their further understanding of those ideas.

Principled knowledge integration

Unlike the "Aliens" design project in Study 1, the "All The News" critique project tended to elicit a relatively standard response in terms of the number of principles considered applicable by most students. The quality measure used in Study 2, then, is the degree to which the principles were linked to cites of the students' other knowledge (such as labs they had done in class or experiences from their daily lives).

Students in the SMP condition in the "All The News" project were significantly more likely than those in the AP condition to exhibit evidence of *principled knowledge integration*. Principled knowledge integration is defined as knowledge integration around one or more scientific principles and is indicated by the combinations of cites used in the explanations. In particular, the analysis investigates whether principles were used in the explanations, and if they were, how many other types of appropriate cites there were in the explanations (cf. Clark, 1996). Of course students may not express all the cites they are building on; the principled knowledge integration measure simply provides our best insight into students' integration of their knowledge.

The AP group gave significantly more principle-only explanations than the SMP group, whereas the SMP group gave significantly more explanations exhibiting principled integration ($\chi^2 = 7.83$, df = 3, $p < 0.05$). That is, the SMP group tended to explain phenomena using a principle and one or more other types of cites, such as everyday experiences or laboratories done in class.

Although the difference is reduced to only a trend when the results are combined (comparing all explanations exhibiting principled knowledge integration with all those not exhibiting it, rather than considering each individual type of explanation separately), the results are still striking. (See Figure 2.) The SMP group tended to exhibit greater evidence for principled knowledge integration. The AP group, on the other hand, tended to either use a single principle (without other cites) or no principles.

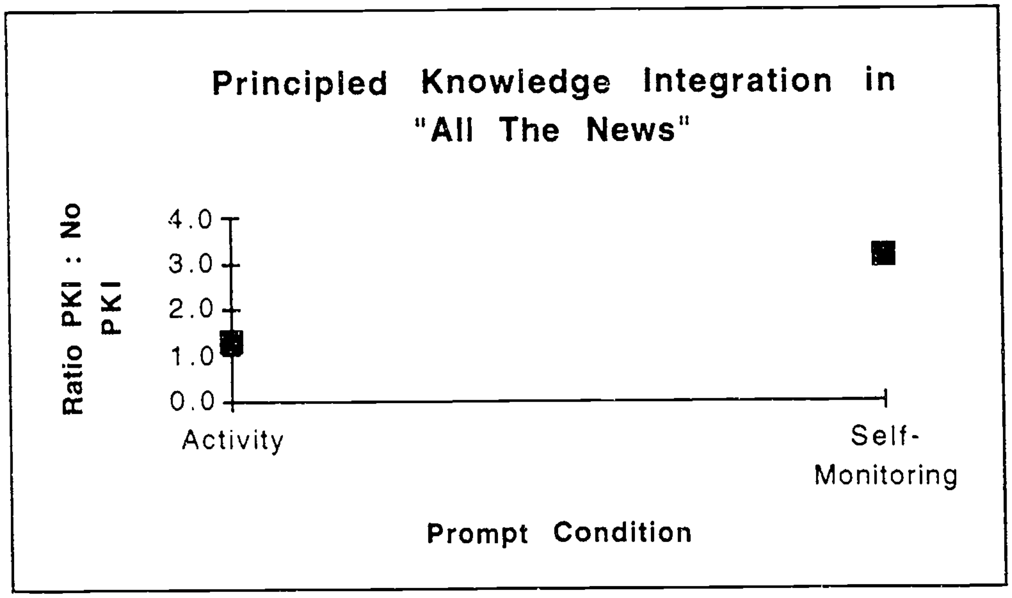

Figure 2: Principled Knowledge Integration

It appears that self-monitoring prompts encourage students to demonstrate or develop an integrated understanding of the science concepts. These prompts may foster a "think-through" approach to the project, as compared to the "walk-through" approach engendered by the activity prompts.

Guidelines written in ATN

The "All The News" project required students to write to the imaginary reporters with guidelines for using evidence. The guidelines were meant to be specific, in order to be as helpful to the "reporters" as possible. Using a Fisher Exact test, the AP group was significantly more likely than the control group to include *multiple* guidelines ($p < 0.04$). However, the control (beliefs prompts) group made significantly *more specific* guidelines than the AP group ($p < 0.03$). There is a strong trend for the control group to make more specific guidelines than the SMP group, as well ($p < 0.1$). There was no difference between the AP and SMP group in the number or specificity of guidelines made.

Thus, students in AP condition wrote significantly more numerous, but also more general, guidelines than did the control group. For example, students in the experimental groups might write "Make the evidence true and relevant" while students in the control group might write "Be sure to control your variables", which gives a specific suggestion for a way to make sure the evidence is "true." While both types of responses are valid, the latter would be more useful if one were learning to use evidence.

It appears that the activity prompts were more likely to help students write *more* guidelines, but that their guidelines were not any *better*. This trend is also, however, true of the SMP group. Different explanations may apply to these two findings. It may be that students receiving self-monitoring prompts got stuck in a the more abstract mode of thinking required by self-monitoring prompts. The activity prompts, which influence the "quantity" of students' work in the overall project coding, may have simply encouraged a "more is better" approach.

Major Dimensions of Self-Monitoring Prompt Responses

How might the self-monitoring prompts encourage these different types of thinking? To gain understanding of the mechanism at work, students' responses to the prompts themselves were reviewed.

In Study 1, the self-monitoring prompts in the "Aliens" project were very successful in their stated goal: more than half of the "plan ahead" prompts involved a restatement of the goal of the activity on which they were embarking, and most of the "look back" prompts involved students reflecting on their projects and asking valid logistical questions about the procedures involved in completing the project. Other reflections included (mostly unelaborated) suggestions for improving their designs.

Some interesting themes fall out of a more comprehensive review of the self-monitoring prompt responses in the "All The News" project in Study 2. These themes can help us begin to understand how self-monitoring prompts might foster an integrated understanding in students. Although not all of the responses indicate that students are taking an integrative view of the project, there are numerous instances in which this happens. And, importantly, even the more detail-oriented responses to the self-monitoring prompts could also help students identify, clarify, and understand the goals of the project and the activities. Thus, both types of responses are valid and useful to varying degrees.

Characterizing students' responses to the self-monitoring prompts also helps us identify refinements to encourage the most useful kinds of thinking. Clearly prompts can be interpreted in different ways (as the following examples will amply show). The goal is to develop a program of prompts that is most likely to help students to take whatever steps are appropriate for them to move toward an integrated understanding. Different programs of prompts may benefit different students.

Some of the major dimensions are discussed and exemplified here. Extreme responses are presented as examples; however, it is important to remember that responses fall in a range along each dimension. (Students' responses are more clear when taken within the context of the article they were critiquing. The text of the article is included in Appendix D.)

Elaborated versus unelaborated responses

Self-monitoring prompts can elicit elaborations. Some students merely "fill in the blank", while others give a more complete explanation of their response:

> Pieces of evidence or claims in the article we didn't understand very well included... the anti-heat shirt claim, and the greenhouse effect claim. (UNELABORATED)

> Pieces of evidence or claims in the article we didn't understand very well included... some of the evidence was unclear and badly represented. Also the chemicals in the anti-heat shirt

were not explained and we didn't really know why it is so great of a shirt. A black oven does not attract heat away from the house. (ELABORATED)

The information we need to include in our critique is stuff like... three pieces of evidence and claims they support. (UNELABORATED)

The information we need to include in our critique is stuff like... what we thought about the evidence. Also what was wrong about the claims. We need to include what we thought was done well. (ELABORATED)

The information we need to write in our letter includes... what was scientific and non-scientific on the different evidence and claims. EX. The graph was scientific, the opinion was not. We will include the basic rule for writing scientific articles. That is to use facts not opinions. (ELABORATED)

Generally, elaborated responses would appear to be more useful in helping students develop a deeper, more integrated understanding.

Analysis of individual ideas versus integration of multiple ideas

Self-monitoring prompts can encourage knowledge integration, both directly and indirectly. Some students discuss individual concepts or pieces of evidence while others integrate (or indicate a desire to integrate) their knowledge. Integration might involve multiple principles or pieces of evidence, or it might link students' real-life experiences with a particular concept under consideration.

Pieces of evidence or claims in the article we didn't understand very well included... the thing about how black colors absorbs heat instead of attracting heat. Is there really a difference? (ANALYSIS)

Pieces of evidence or claims in the article we didn't understand very well included... what the greenhouse effect has to do with solar oven. (INTEGRATION)

Pieces of evidence or claims in the article we didn't understand very well included... why do we need to cook outside with that special stove because we don't believe it makes a difference, you could use a grill instead. The evidence we didn't understand we wrote in our other notes. (INTEGRATION)

We would have understood the article better if... you told us which chemical the anti-heat shirt had. (ANALYSIS)

We would have understood the article better if... they would explain how the light energy matters about heated up the house. Maybe they should give out examples and evidence. (INTEGRATION)

Students reap benefits from both types of analysis. If students identify specific science concepts they do not understand, they move one step closer to developing an understanding of that concept. However, by taking an integrative approach, students may clarify their goals for the project as a whole which may help them to integrate their knowledge. Students may also identify aspects of their understanding that could be linked, refined, or reconciled. Integration is obviously important, and a deep understanding of individual pieces provides the foundation for that integration.

New attitudes toward learning versus traditional attitudes

Self-monitoring prompts can facilitate articulation of students' attitudes toward learning and working on the project. Some students appear to have a traditional view of school, seeing the project as a set of paces to be made. Some similarly put the onus of responsibility for their learning on others. Others demonstrate a new attitude, adopting a knowledge integration approach, going beyond the requirements of the project, and taking personal responsibility for their learning.

> To do a good job on this project, we need to ... look at all the evidence, follow the directions given, and do our best to complete every step. (TRADITIONAL)
>
> The part of critiquing that 's hardest for us is... that we are supposed to have a curious eye on every aspect of the article. For us that is new and hard for us and it is hard to cope with that. We think that with time and effort we will be better critiquers and have a curious eye on everything. (NEW)
>
> To answer those questions we will... ask Mr. K. (TRADITIONAL)
>
> To answer those questions we will... look back to our old labs and look at the information more carefully and see if there is any new evidence. (NEW)

Most students encouraged in the traditional mind-set since they started school; it is not at all surprising that they often view science as a collection of facts to be memorized (Davis, 1995; Linn & Songer, 1993; Songer & Linn, 1991) and science projects as yet another opportunity to fill in the blanks. KIE projects attempt to foster a change in these attitudes. To whatever extent the students exhibit an understanding of these new learning goals, they may also prove more likely to work to achieve the integrated understanding encouraged by those goals. While "following the directions given" may be a good idea, "having a curious eye" may be more likely to facilitate the integration of knowledge.

Influences on prompt development

How will these findings influence the program of self-monitoring prompts students experience? Since prompts are interpreted by individual students, we cannot be certain of developing foolproof "integration" prompts. However, investigating the trends visible in the prompts—and seeing how different students understand and respond to them–allows refinement of the prompts to move toward that goal. Prompts should help students elaborate on their thinking and encourage an integrative stance without eliminating the use of an analytic stance. Such self-monitoring prompts may help students see and articulate the new goals of science and may help them to achieve an integrated understanding of the science concepts under consideration.

Discussion

This set of investigations shows that metacognitive prompts have both strengths and weaknesses. Activity prompts help students finish activities but do not necessarily help the students to develop an integrated understanding. Self-monitoring prompts encourage students to plan their activities, remind students to reflect on their own understanding, and improve students' likelihood of explaining and justifying the decisions they make. These results have directly affected the design of the KIE software and projects. However, merely identifying the effects of the two types of prompts is insufficient to fully improve students' learning conditions. We must also investigate the cognitive mechanisms by which the prompts work. The two research questions framing this research addressed both of these issues, and will be reviewed now.

First, prompts do have specific effects. The results reported here indicate that while activity prompts guide students to complete the important pieces of a project, self-monitoring prompts encourage them to link those pieces and integrate their knowledge. Both prompt types help some students more than others. And, findings from Study 1 indicate that the two types of prompts may have a synergistic effect, as well.

But how can we explain these instructional effects? Activity prompts may lessen the cognitive load on students, helping them to identify how to accomplish the steps necessary for an activity and to remember to do each of those steps in the first place. These prompts may, however, encourage a piecemeal view of the process, by emphasizing each step rather than how the steps work together to achieve a particular goal. The students may have an integrated understanding of the concepts, but if that is the case they do not demonstrate it.

On the other hand, self-monitoring prompts help students integrate their knowledge around principles or demonstrate such an understanding. Since the self-monitoring prompts used in the studies do not *directly* elicit integrated knowledge, it appears that students simply need scaffolding to think about their goals for a project and their progress on that project, topics on which students are not generally requested to think. Perhaps as a result, they are better able to integrate their understanding. In fact, some students indicate in their responses to self-monitoring prompts that they are aware that the KIE projects require them to embark on a different, more integrative type of thinking, as indicated by the students who are struggling to develop a "curious eye." It may be that self-monitoring prompts help students view KIE projects differently from how they typically view school projects—a "think-through" approach—and thus engage in the task in an inherently different way.

The implied synergistic effect may indicate that at least some students benefit from both aspects of metacognitive prompting. Students may attain an improved understanding of their goals through "planning ahead" prompts, make appropriate steps toward those goals through activity prompts, and improve their understanding and their work through "looking back" prompts.

Further work is necessary to better understand the effects of the two types of metacognitive prompts, in particular the possible synergy. One last large question must be addressed, as well: What influences the benefits students reap from different types of prompts? I hypothesize that different students will benefit from different prompts or mixes of prompts, based in part on their beliefs about science and about learning science. Those beliefs may influence how students go about doing science, which in turn would influence their use of prompts.

Specifically, based on the results discussed here and other related research, I hypothesize that activity prompts are necessary for some students who would not otherwise complete the process required by the project, but that self-monitoring prompts may help some students (who may already be proficient at the process required) look at the bigger picture. I further hypothesize that self-monitoring prompts may benefit some students who do *not* exhibit proficiency at or understanding of the process of science, by encouraging them to clarify the overall goals of each activity on which they are embarking and reflecting on how each activity moves them toward completion of the final goal. I also hypothesize that a mix of activity prompts and self-monitoring prompts may be most beneficial to some students, who need a bit of the process guidance provided by the activity prompts but have the ability to reflect on and integrate their understanding, as encouraged by the self-monitoring prompts. It may be that this mix is beneficial for a majority of the students. Last, I hypothesize that some students do not need either type of prompts. These students may find self-monitoring prompts irrelevant (because they already know how to manage a large project) and activity prompts stifling (because they already know how to take the necessary steps).

Both types of prompts can interrupt independent reasoning and distract students who already understand what steps to take. Contextualized prompting, while often helpful, thus requires judicious use of prompts. Studies are underway to further investigate the effects of metacognitive prompts. In particular, work is ongoing in the identification of relationships between students' responses to the self-monitoring prompts and the work they do on the projects, the relationship between completion and project quality within individuals, and students' views of the purposes of the prompts themselves. Results of this work will further our understanding of how to foster metacognitive activity for individual students.

The research described here, in conjunction with the work in progress, will improve KIE students' learning opportunities by improving both the curriculum materials (in particular, the prompts) and the software itself (the cognitive guidance system). Through careful analysis of how students respond to particular types of prompts, we can develop curricula suited to their particular needs. Students who would benefit most from a particular type of prompt (or a mix of prompts) would receive that program. Students may also benefit from being challenged to experience prompts with which they may not be comfortable, to help them develop new ways of thinking.

The research may also affect the design of instruction by educators not associated with KIE. Understanding the benefits of the two types of metacognitive prompts described here may encourage instruction using activity-like prompts and self-monitoring-like prompts. Some students may be benefited by being explicitly prompted for metacognitive activity.

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Appendix A: An "Aliens" Document

Design Dwelling
by Student-1 & Student-2
KIE period:

Planning Ahead: In thinking about our doing our design, we need to think about...

Your assignment is to use the evidence you've seen to design a dwelling for the aliens to make their visit on Zumtar as enjoyable and comfortable as possible.

You need to think of suggestions and designs which would be most helpful in maintaining the aliens' ideal temperature throughout the day and night (don't forget about the air blast that happens every morning and evening).

Your design should include what type of material you choose for the walls of the dwelling, recommendations for paint colors, and information on the temperature of the air blast given. All recommendations should be backed up with scientific evidence or thoughts. The same dwelling must work for ALL aliens (you can, however, customize different aliens' apartments through the air blast you give them).

Don't forget to check with Mildred for help in working on this!

Dwelling Design:

write dwelling design here

when you're done with the dwelling design:

My design will be good for the different kinds of aliens because...

Looking Back: Our design could be better if we...

Appendix B: An "All The News" Document
(Activity Prompt Condition)

Letter to the Newspaper
by Student-1 & Student-2
KIE period:

Your task now is to write a letter to the newspaper on how the article could be improved.

The letter should talk about how each piece of evidence you critiqued helped (or didn't help) the claims the article was making, and how the claims help the overall argument. If a piece of evidence should be taken out, or if a claim in the article needs to be rephrased, explain why. Remember, the Weekly World Science News is trying to get their reporters writing more believable and more scientific articles. Your summary should provide a set of guidelines for the reporters to follow in the future.

Don't forget to check with Mildred for help in working on this! Mildred includes hints on what could be included in each section as well as things to remember when you're making suggestions to the people at the newspaper.

The headings and prompts here are meant to be suggestions. You should use your own style to write the report!

Dear Weekly World Science News,

Section 1: Introduction

[Thank you for the opportunity to help the Weekly World Science News. We have some suggestions that will make your paper's article much more believable and scientific. We will try to explain our suggestions really well so the reporters will be able to learn what they should do in the future.]

Section 2: The Evidence, the Claims, and the Overall Argument

[Here, we'll present each of three pieces of evidence in turn, explaining why each helps (or doesn't help) the reporters make the claims in the article. And, we'll say why each piece of evidence or claim should (or shouldn't) be included in the article.]

[Evidence-1...]

[Claim-1...]

[Evidence-2...]

[Claim-2...]

[Evidence-3...]

[Claim-3...]

[Now, we'll talk about the overall argument, and how the claims and evidence support or don't support the argument of the article.]

[The argument...]

[Readers would get more from the article if the article...]

Section 3: Evidence Guidelines for the Reporters

[Now, we'll give you a set of guidelines that your reporters should follow when they use evidence.]

[When you think about evidence, in general you should make sure to consider...]

[When you write an article based on evidence, the article should...]

Section 4: Conclusion

[We hope our report on your paper's article is helpful. We tried to provide information on which evidence and claims are scientifically OK and which are bogus. We also tried to give you reasons for every decision or suggestion we made. We tried to keep reporters in mind as we wrote our reports, so it would be appropriate for you. We tried to make our suggestions and comments very clear.]

Sincerely,
[your names]

Appendix C: An "All The News" Document
(Self-Monitoring Prompt Condition)

Letter to the Newspaper
by Student-1 & Student-2
KIE period:

Planning Ahead:
Thinking Ahead: Specific things we need to think about as we write our letter include...

What to Include: The information we need to write in our letter includes...

Writing the Letter:

Your task now is to write a letter to the newspaper on how the article could be improved.

The letter should talk about how each piece of evidence you critiqued helped (or didn't help) the claims the article was making, and how the claims help the overall argument. If a piece of evidence should be taken out, or if a claim in the article needs to be rephrased, explain why. Remember, the Weekly World Science News is trying to get their reporters writing more believable and more scientific articles. Your summary should provide a set of guidelines for the reporters to follow in the future.

Don't forget to check with Mildred for help in working on this! Mildred includes hints on what could be included in each section as well as things to remember when you're making suggestions to the people at the newspaper.

The headings and prompts here are meant to be suggestions. You should use your own style to write the report!

Dear Weekly World Science News,

Section 1: Introduction

[*Thank you for the opportunity to help the Weekly World Science News. We have some suggestions that will make your paper's article much more believable and scientific. We will try to explain our suggestions really well so the reporters will be able to learn what they should do in the future.*]

Section 2: The Evidence, the Claims, and the Overall Argument

[Here, we'll present each of three pieces of evidence in turn, explaining why each helps (or doesn't help) the reporters make the claims in the article. And, we'll say why each piece of evidence or claim should (or shouldn't) be included in the article.]

[Now, we'll talk about the overall argument, and how the claims and evidence support or don't support the argument of the article.]

Section 3: Evidence Guidelines for the Reporters

[Now, we'll give you a set of guidelines that your reporters should follow when they use evidence.]

Section 4: Conclusion

[We hope our report on your paper's article is helpful. We tried to provide information on which evidence and claims are scientifically OK and which are bogus. We also tried to give you reasons for every decision or suggestion we made. We tried to keep reporters in mind as we wrote our reports, so it would be appropriate for you. We tried to make our suggestions and comments very clear.]

Sincerely,
[your names]

Looking Back
Checking Our Understanding: Questions we still have are...

Improving Our Understanding: To answer those questions, we will...

Checking Our Work: In looking back at what the editor wanted, we think she will like our letter because...

Checking Our Work: The editor might not like...

How We Spent Our Time: As we worked on this project, we wish we'd spent more (or less) time on...

Appendix D: The "All The News" Article

Keeping Your Cool in the Summertime

by Rocky Reporter and Jana Journalist

Summer is a time for fun and sun, but when it gets too hot, watch out! We've figured out how to beat the heat this summer. To keep your house cool this summer, do your cooking outside. Outdoor cooking attracts heat away from the house and keeps everyone cool. The new solar ovens are the best, using up lots of heat that would otherwise heat houses.

Claim 1: Energy conversion principles indicate that black attracts heat

When made correctly, solar ovens use energy conversion principles to put heat to good uses. Solar ovens often have black lids to make them heat up faster. We asked local residents why the black lids worked. One woman interviewed reports, "I've seen it happen myself. When my friend Bill and I went to the beach, Bill stayed cool longer in his white T-shirt than I did in my black dress." Obviously, black items attract the heat better than white items.

Claim 2: Heat sources cause the temperature to go up

Why move the ovens outside? Everyone knows that anything that gives off heat will heat up the space it's in. So since ovens heat up kitchens, moving them outside will cool the house down. This works best in houses with small kitchens since studies show that heat sources heat up small rooms faster than large rooms.

Claim 3: Ovens and other objects use up sunlight, thereby lowering temperatures

The third point, then, is that having a solar oven outside would keep your house cool by using up some of the sunlight that would otherwise have entered your house and made it hot. Students performing an experiment on the greenhouse effect determined that the heat can be trapped in containers where light can get in easily but heat can't get out. We've experienced the same phenomenon when we left our cars in the sun with the windows shut; the heat built up quickly. If possible, leave the windows open and the shades drawn so less sunlight comes in. The solar oven uses up heat in a way similar to how the new "anti-heat" shirt does. The shirt reportedly keeps you cool because it is dipped in a special chemical. The manufacturers say that this chemical can keep you cool even in the hottest weather.

You can see, then, that the answer to the question "How can I stay cool in the summertime?" is clear. Just cook with a solar oven and use other items to use up the sunlight, and you'll stay nice and cool while everyone else is sweating.