Encouraging students to be autonomous is an important goal of the scaffolded knowledge integration framework. Knowledge integration requires students to expand their repertoire of ideas but unless those ideas are reflected upon, they cannot be linked to and reconciled with current ideas. Students are capable of doing this kind of reflection but, many need scaffolding. Scaffolding—here in the form of reflection prompts—can help students be autonomous integrators of their knowledge. This research investigated learning and design questions. It determined whether reflection prompts promote knowledge integration for students working on science projects and investigated the effects of students’ different dispositions on their reflection. It explored which characteristics of prompts best support students in knowledge integration.

The learning results indicate that prompting students to reflect significantly increases knowledge integration in science projects. Yet similar prompts elicit qualitatively diverse responses from students. Students who focus on their ideas perform significantly better on the end product than do other students who focus on their actions or activities. Furthermore, students who indicate that they understand everything perform significantly worse on the final project than do other students. The design results show that self-monitoring prompts, which encourage planning for and reflection on activities, help students to demonstrate an integrated understanding of the relevant science; while activity prompts, which guide the inquiry process, are less successful in prompting knowledge integration.

**Introduction**

When students reflect on their ideas they generally produce better products. We postulate that prompting students to reflect can set this process in motion. The process of reflection on ideas, we suggest, motivates students to revisit, test and, reformulate the links and connections among their ideas leading to more coherent, integrated understanding. This research includes learning studies to clarify how prompts facilitate knowledge integration and, design studies that identify the features of effective prompts. We report on three studies of the impact of prompts delivered to students doing projects in middle school science classes using the Knowledge Integration Environment (Bell et al. 1995).

**Promoting knowledge integration with prompts**

We view science learning as a process of integrating ideas. To integrate ideas, students add information, reorganize information, promote some ideas and,
demote other ideas. The ideas students bring to science class get linked to new ideas, are combined with each other and, reorganized. We investigate how prompts influence this process (see Davis 1998 for a more complete discussion of this work).

Students, for example, may come to science class believing that black shirts feel hotter than white shirts at the beach. When they study energy conversion they may add the idea that light energy is converted to heat energy when it is absorbed. They may also know that at night it is easier to see someone wearing white than it is to see someone wearing black. When prompted to reflect, a rare student might connect the observation of white being more visible than black at night to ideas about light reflection and conclude that only absorbed light is converted to heat, remarking, ‘white reflects more light, so less light is available to be converted to heat with a white shirt’. Other students might equate light with heat and discount the energy conversion experiment done in class, remarking, ‘heat from the sun is absorbed by black but not by white’. Most students need many opportunities to reflect in order to build cohesive, coherent accounts of new material.

Knowledge integration involves differentiating, integrating, and restructuring ideas. In this process, students expand their repertoire of ideas, discriminate between ideas and, reorganize the links among them (Linn and Eylon 1996). Expansion of the repertoire of ideas is necessary but not sufficient (Hsi 1997). Some students are content to accept any idea presented, without consideration of whether that idea makes sense on its own or how it fits with other ideas. These students are less successful at developing an understanding of scientific phenomena than are students who identify weaknesses in their current knowledge, reflect on new ideas, working to understand each concept and, determine places where links can be made among the ideas, thus improving their knowledge integration.

From research designed to promote knowledge integration we have formulated the scaffolded knowledge integration instructional framework that guides this research. The framework involves four elements (Linn 1995; 2000). First, instruction should ‘make thinking visible’ to students by illustrating how links and connections are made. Teachers and students reasoning about scientific phenomena need to reveal their own thinking to themselves and their peers. Secondly, instruction should make science accessible, identifying models for scientific phenomena that make sense to students so they can connect new information to existing knowledge and to problems that are both familiar and relevant. Thirdly, instruction should provide social supports so all students learn new links and connections for their ideas from their peers. Finally, students should be encouraged to become autonomous learners so they can regularly revisit their ideas and continue engaging in knowledge integration.

Although prompts contribute to each of the tenets of the scaffolded knowledge integration framework, they particularly encourage autonomy by modelling reflection and providing an explicit place for reflection. We also hope they help students to develop the propensity to continue linking ideas and evaluating views autonomously. To promote autonomy, we designed prompts that students would encounter at several points while they conducted science projects. Prompts were designed to encourage reflection with the idea that regularly engaging in reflection would illustrate the advantages of reflection and lead to autonomous reflection in the future.
In this research we report on two types of prompts: ‘activity’ and ‘self-monitoring’. Activity prompts encourage students to reflect on their progress in the activity and specifically about whether they have devoted attention to each aspect of their project. For instance, an activity prompt in the context of an activity in which students were writing a critique of an article might ask, ‘readers would get more from the article if the article...’. Self-monitoring prompts encourage students to reflect on their own learning by asking, for example, ‘the part of critiquing that’s hardest for us is...’.

Our research investigates how students respond to prompts and whether prompts help students do better projects. We ask whether activity prompts help students complete all the pieces of a project and, whether self-monitoring prompts encourage knowledge integration. We determine whether students who focus on their ideas create higher quality projects than do other students. We assess whether self-monitoring prompts help students expand their repertoire of ideas, making sense of each new, individual idea and, reflect on how the new ideas can be integrated into their current knowledge. We find that self-monitoring prompts do encourage knowledge integration and, that students’ reflection in response to these prompts plays a role in their knowledge integration. Students who focus on project ideas are more successful at integrating their knowledge.

Relevant research

Encouraging reflection has been the focus of many research programs. For example, questions from teachers, peers, software, or texts can promote knowledge integration by eliciting explanations. Students who provide explanations to other students’ questions or who explain examples they find in their textbooks appear to strengthen connections among their ideas. Research indicates that prompts or questions that elicit self-explanations lead to improved understanding of texts (Chi et al. 1989, Chi et al. 1994, Webb 1983). Bielaczyc et al. (1995) found that students can be trained to give self-explanations when learning the LISP programming language, and that this training promotes improved understanding.

In classrooms, several delivery systems for prompts have also improved reflection. Reciprocal teaching, used most often in reading classes, requires students to prompt each other to explain using a set of general questions that can be asked about any kind of paragraph (Brown and Palincsar 1989). In the CSILE (Computer Supported Intentional Learning Environment) programme learning environment, students choose prompts based on their own goals (Scardamalia and Bereiter 1991). Research by both of these groups indicates that students make better connections among ideas from instruction using prompts. Others have successfully used prompts, delivered in various ways, in order to encourage students to reflect on their problem-solving processes, inquiry methods and, lab work (Collins et al. 1991, Gunstone et al. 1992, Schoenfeld 1987, White and Frederiksen 1998).

To help students integrate knowledge, instructors must select the right level of analysis for instruction. Linn and Clancy (1992) have found that students are most successful at learning programming when they discuss specific prototype problems rather than abstract approaches. An unpublished study by one of the authors (Davis, personal communication) found that students benefit from contextualized prompts which help them clarify and focus their thinking. Clark (1996) found that
students revise their work more often in response to prompts that make specific suggestions. And, in reciprocal teaching, students internalize a programme of prompts for a particular activity—for example, reading a passage (Brown and Palincsar 1989). All of these research efforts point to the value of specific, contextualized prompts over abstract prompts.

White and Frederiksen (1998) have shown success using prompts for reflective assessment in their mechanics curriculum for junior high school students. Students who routinely answered such prompts developed greater understanding of the subject matter and of the inquiry process. Tien et al. (1999) explicitly encouraged students to articulate a model of their current understanding of a chemical process and to reflect upon the implications of their observations on their conceptual model. Students who engaged in these and other innovative activities appeared to develop a greater conceptual understanding than did those students in a traditional college chemistry course. Lan (1996) found that students who were scaffolded in self-monitoring did better in exams and had better representations of their knowledge. Other researchers have also discussed the benefit to students’ understanding of explicit planning and monitoring (e.g., Bielaczyc et al. 1995; Brown and Palincsar 1989) and, the positive effects of planning on writing in particular (Flower and Hayes 1980).

The Computer as Learning Partner project has long used sentence-starter prompts to foster reflection. Originally, Computer as Learning Partner prompts encouraged students to make predictions and reconcile their data with those predictions, important aspects of knowledge integration. These prompts proved successful at encouraging students to integrate their knowledge. Later, the Computer as Learning Partner implemented prompts for each aspect of completing a lab, and again, students’ understanding improved (Linn and Songer 1991).

The Knowledge Integration Environment (KIE) software and curricula have developed directly out of the Computer as Learning Partner’s years of research on designing curricula and technology for middle school science teaching and learning. The prompts used in KIE build on the Computer as Learning Partner experiences as well as those of other researchers. KIE projects are more open-ended than Computer as Learning Partner labs, less activity-driven than summarizing a passage in reciprocal teaching and, more directed than the ‘knowledge-building’ of CSILE. Thus, KIE requires prompts that explicitly encourage students to make explanations and to reflect at selected points as they work on complex projects.

KIE prompts are closely coupled with specific parts of a project, such as critiquing evidence. The activity prompts guide students to identify appropriate, detailed considerations as they work on individual activities within the context of a large project. An activity prompt might, for example, ask students to justify their decision or write a scientific explanation of a decision. Activity prompts play different roles for different students: a prompt for justification may remind some students to describe their justification while motivating others to seek a justification.

KIE’s self-monitoring prompts are planning and monitoring 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. These prompts may act as a ‘more able other’, prodding the students to consider issues they may not have considered otherwise (cf. Vygotsky 1978). That is, these prompts may give students a better understanding of the kinds of questions they should be addressing.

Thus, prompts can serve two roles in achieving the overarching goal of knowledge integration: they provide the impetus for explanation and, they encourage reflection at a level that students do not generally consider.

Methods
We designed three studies to assess learning from activity and self-monitoring prompts and to determine good prompt design. This section will discuss the students’ classroom experiences as part of the studies, the designs of these studies and, how the effects of prompts were evaluated. In each study, the prompts were delivered through the Knowledge Integration Environment. We turn first to a description of KIE and the classroom in which this research took place.

Learning environment
Using the Knowledge Integration Environment students complete week-long projects drawing on scientific evidence from the World Wide Web (Bell et al. 1995). 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. KIE projects are designed to encourage a deep understanding of science concepts rather than a collection of 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 into three major categories: critique, debate and, design projects. Critique projects foster the development of a critical eye when using evidence and evaluating arguments. Theory comparison projects 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, guided by scientific evidence.

In the classroom in which this research took place, KIE provided capstone projects for the Computer as Learning Partner curriculum. The Computer as Learning Partner provides a one-semester curriculum introducing the physical science topics of thermodynamics and light to eighth graders (Linn and Songer 1991). In the curriculum, which is laboratory-based, students use the computer as a tool to collect and graph real-time data, perform simulations of experiments and, help them track their progress. The three studies took place in different semesters of this eighth grade class. In all cases, students usually worked in pairs but occasionally worked alone or in triads.
Self-Monitoring Prompts encourage planning and reflection:

Thinking ahead: To do a good job on this project, we need to 
Thinking ahead: To do a good job on our letter, we need to 
Checking our understanding: Pieces of evidence or claims in the article we didn’t understand very well included 
Checking our understanding: In thinking about how it all fits altogether, we’re confused about 

Activity Prompts facilitate completion of specific aspects of the activity:

The letter says we need to 
The major claims made by the article include 
Overall, we think the first evidence/claim we critiqued 
Claim 1 should say 

Figure 1. Examples of prompts.

Figure 2. KIE guidance system.

Prompt delivery

The three studies assess the relative success of activity and self-monitoring prompts. KIE prompts appear in the form of sentence-starters. Students write responses that complete the sentences and figure 1 presents a sample of the prompts of each type. Self-monitoring prompts typically fall before and after the activity itself (i.e. the sequence for a ‘critique evidence’ activity might be: first, a ‘thinking ahead’ prompt; second, critiquing the evidence; and third, a ‘checking our understanding’ prompt). Activity prompts, on the other hand, compose part of the activity itself.

In Studies 1 and 2, prompts were included in word processing files students worked with as part of the project, while in Study 3, prompts were delivered through a more sophisticated guidance system called Mildred, which give access to relevant hints as well as providing note-taking capabilities (see figure 2).
In both cases, students typed in responses. They could easily change the words in the prompt, although relatively few students chose to do so.

**The projects**

Each study took place in a different semester, with different students. We studied two different KIE projects. In study 1 students did a design project called ‘aliens on tour’. In this project, students design houses and clothing for three sets of cold-blooded aliens with different climate requirements. The students review a range of evidence (from an advertisement for ‘anti-heat ice cloth shirts’ to a table of R-values). They then create their designs, combining the evidence with ideas from Computer as Learning Partner labs on insulation, conduction, energy conversion and, heat flow.

In studies 2 and 3, students did a critique project called ‘all the news’. Students critique evidence cited by a fabricated news article about energy conversion and elementary thermodynamics. The project involves reading the article to be critiqued and looking at its concomitant evidence about heat flow and energy conversion, critiquing the evidence and the claims being made and, writing a letter to the imaginary editor with a synthesized critique and giving guidelines for future use of evidence. After study 2, the project was slightly revised for instructional purposes but, the overall instructional goals and design remained the same for study 3.

**Study designs**

Study 1 compared the effects of self-monitoring prompts and activity prompts on project success. We investigated whether eighth graders are able to plan and reflect on their progress and whether planning and reflecting helped students in their work. We contrasted self-monitoring prompts focusing on planning and reflection, with activity prompts focusing instead on the justification of decisions.

In study 1, as students completed each design, they 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. The activity prompt stated, ‘our design will work well because…’. In addition, half of the students in study 1 received a total of 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 think about the activity on which they were embarking. A plan ahead prompt used in the design activities 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…’. Figure 3 summarizes the prompts that the students in the two conditions saw for the clothing design.

Thus, in study 1, we investigated two conditions: one group received only activity prompts, and the other received self-monitoring prompts in addition to the activity prompts.
Study 2 replicated and extended study 1, and was informed by the previous study’s results. We undertook study 2 for three purposes: to test a refined set of prompts in a different project, with the intent of comparing students’ responses in different contexts; to investigate separately the activity and self-monitoring prompts to identify their individual strengths and weaknesses; and, to create activities that would allow students in each condition to spend comparable amounts of time on the actual project work itself.

As we gained a better understanding of their effects, we improved the prompts used. In study 2, unlike study 1, the activity prompts included not just prompts for justification but for all the steps necessary to do a good job on the critique project. Students, for example, were prompted for a discussion of the article with the prompt, ‘readers would get more from the article if the article...’. We also refined the self-monitoring prompts in study 2. The basic change was to include thinking types before each prompt, similar in nature to those used in the CSILE program (Scardamalia and Bereiter 1991), to cue students as to what kinds of planning and reflection are important. The examples of thinking types included, ‘thinking ahead’, ‘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 the activity was, ‘in looking back at what the editor wanted, we think she will like our letter because...’.

The control condition in study 2 used a set of ‘belief prompts’ to ensure that all students responded to approximately equal numbers of prompts. These prompts asked students about their beliefs concerning the use of and critiquing evidence and, an example prompt was, ‘if two people believe two different claims, it means...’. Belief prompts were unlikely to influence students’ work on the rest of the project.

**Figure 3. Instructions for clothing design for the two conditions in study 1.**

<table>
<thead>
<tr>
<th>Self-monitoring + activity prompt condition</th>
<th>Activity prompt condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning ahead:</strong></td>
<td></td>
</tr>
<tr>
<td>In thinking about doing our design, we</td>
<td></td>
</tr>
<tr>
<td>need to ...</td>
<td></td>
</tr>
<tr>
<td><strong>Design report</strong></td>
<td></td>
</tr>
<tr>
<td>Your assignment now is to use the evidence</td>
<td>Your assignment now is to use the evidence</td>
</tr>
<tr>
<td>you’ve seen to design clothing for the aliens</td>
<td>you’ve seen to design clothing for the aliens</td>
</tr>
<tr>
<td>to make their visit to Zumtar as enjoyable</td>
<td>to make their visit to Zumtar as enjoyable</td>
</tr>
<tr>
<td>and comfortable as possible... You can</td>
<td>and comfortable as possible... You can</td>
</tr>
<tr>
<td>design different clothes for the different</td>
<td>design different clothes for the different</td>
</tr>
<tr>
<td>aliens.</td>
<td>aliens.</td>
</tr>
<tr>
<td><strong>when you’re done with the design:</strong></td>
<td></td>
</tr>
<tr>
<td>My designs will be good for the different</td>
<td>My designs will be good for the different</td>
</tr>
<tr>
<td>aliens because ...</td>
<td>aliens because ...</td>
</tr>
<tr>
<td><strong>Looking back</strong></td>
<td></td>
</tr>
<tr>
<td>Our design could be better if we ...</td>
<td></td>
</tr>
<tr>
<td>Questions we still have are ...</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 3. Instructions for clothing design for the two conditions in study 1.*
Self-monitoring prompt condition

Planning ahead:
What to Include: The information we need to write in our letter includes . . .
Thinking Ahead: To do a good job on our letter, we need to . . .

The letter should
• talk about how each piece of evidence you critiqued helped (or didn’t help) the recommendations the article was making, and whether the claims made sense. If a piece of evidence should be taken out, or if a claim needs to be rephrased, explain why.
• give suggestions for how to re-write the claims.
• provide a set of guidelines for the reporters to follow in the future.

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.]

Section 2: The Evidence and the Claims
[Here, we’ll present each of three pieces of evidence in turn, explaining why each helps (or doesn’t help) the reporters make the recommendations in the article.]

Section 3: Re-writing the Claims
[In this section, we’ll tell you how we would re-write each claim so the public will be getting the best information possible.]

Section 4: Evidence Guidelines for the Reporters
[Now, we’ll give you a set of guidelines that your reporters should follow when they use evidence.]

Section 5: Conclusion
[We hope our report on your paper’s article is helpful.]
Sincerely,
[your names]

Looking back
Checking Our Understanding: We still don’t understand . . .
Checking Our Work: In looking back at what the editor wanted, we think she will like our letter because . . .
How We Spent Our Time: As we worked on this project, we wish we’d spent more time on . . .

Activity prompt condition

Dear Weekly World Science News,

Section 1: Introduction
[Thank you for the opportunity to help the Weekly World Science News.]

Section 2: The Evidence and the Claims
[Here, we’ll present each of three pieces of evidence in turn, explaining why each helps (or doesn’t help) the reporters make the recommendations in the article.]

Section 3: Re-writing the Claims
[In this section, we’ll tell you how we would re-write each claim so the public will be getting the best information possible.]

Section 4: Evidence Guidelines for the Reporters
[Now, we’ll give you a set of guidelines that your reporters should follow when they use evidence.]

Section 5: Conclusion
[We hope our report on your paper’s article is helpful.]
Sincerely,
[your names]

Looking back
Checking Our Understanding: We still don’t understand . . .
Checking Our Work: In looking back at what the editor wanted, we think she will like our letter because . . .
How We Spent Our Time: As we worked on this project, we wish we’d spent more time on . . .

Figure 4. Instructions for letter for the two conditions in study 2.

In study 2, then, we investigated three conditions: one group received activity prompts, another group received self-monitoring prompts and, the third group (the control condition) received beliefs prompts. The total number of prompts was kept constant across conditions. To provide the most direct scaffolding, the activity prompt group was explicitly prompted with sentence-starters for each part of the letter to the editor. 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 (see figure 4 for a summary of the instructions the students saw).

Study 3 investigated the kinds of reflection self-monitoring prompts elicit as well as the relationships between reflection and success on the project. We investigated whether the specific orientation of students’ reflection plays a role in project success. Study 3 closely examined students’ responses to various self-monitoring prompts. Students received an identical set of 11 prompts. The project included six ‘thinking ahead’ prompts, four ‘checking our understanding’ prompts and, a single ‘thinking back’ prompt, which was similar in nature to the ‘thinking ahead’ prompts but was retrospective rather than forward-looking. Figure 5 shows the self-monitoring prompts used in study 3. The self-monitoring prompts were refined versions of self-monitoring prompts that elicited the best responses in earlier trials.

**Figure 5. Self-monitoring prompts in study 3.**

Outcome measures and scoring criteria

We scored overall project success and individual prompt responses. Studies 1 and 2 emphasized project success, whereas study 3 emphasized individual prompt responses. The outcome measures evolved as we gained understanding of the effects of prompts.

Project success. In study 1, we coded the ‘aliens on tour’ clothing and house designs for: (a) level of explanation; (b) number of scientific principles used; (c) conceptual validity; and (d) degree of completion. The level of explanation code indicates whether the explanation given was descriptive or scientific in nature. For instance, a student who says that white cloth will be used ‘to reflect the light energy off of [the aliens]’ gives a scientific explanation, whereas a student who merely lists materials to be used without justifying those choices gives a description-level explanation. The number of principles that could be applied to a design is large and students could, for example, reasonably apply the principles about energy conversion, insulation, conduction, heat flow and, the reflection of light. We simply counted the number of these principles that were applied. We measured conceptual validity based on the degree to which science ideas used by
students matched scientifically normative ideas about heat energy and temperature. We assessed degree of completion by counting the number of sections of the project that were executed following instructional specifications.

In study 2 we scored the letter to the editor using a measure of principled knowledge integration. Specifically, we define principled knowledge integration as the degree to which students like ideas around one or more scientific principles. We investigate whether principles were used in the explanations and, if they were, how many other types of knowledge (such as labs done in class or daily life experiences) were connected in the explanations (cf. Clark 1996). We computed a score based on the presence or absence of linkages between principles and other ideas students cited in their explanations.

For study 3, we first scored the letter to the editor holistically. The holistic project score was based on: (a) conceptual validity (again, the quality of students’ ideas as compared to scientifically normative ideas); and (b) the degree of completion. Then we made a more detailed coding of project success on the basis of firstly, overall critique quality and, secondly, coherence of ideas. We assessed overall critique quality on the basis of how well students addressed the science, methods, and credibility of the evidence and, the validity of the scientific claims. To assess coherence, we identified where students made appropriate links as compared to linking inappropriately or giving contradictory ideas.

**Prompt responses.** In addition to coding students’ project successes, we also scored individual responses to prompts. For study 1, self-monitoring prompts were scored based on the students’ focus (e.g., a goal restatement or a science question) and, the activity prompts were coded for scientific content. For study 2, we refined

<table>
<thead>
<tr>
<th>Focus of reflection</th>
<th>Example of prompt and response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions</td>
<td>To do a good job on this project, we need to.../pay attention/, /do all the work as best as we can/, and /discuss the questions very carefully/.</td>
</tr>
<tr>
<td>Project activities</td>
<td>To do a good job on this project, we need to.../make sure we read the letter and article carefully/ and /make sure we critique each claim/.</td>
</tr>
<tr>
<td>Project ideas</td>
<td>Claims in the article we didn’t understand very well included... /why a small room would heat up faster than a big room/.</td>
</tr>
<tr>
<td>Knowledge</td>
<td>Our evidence critiques will be useful later because... /it will help us be more accurate on other articles than we critique/. /Also to understand how if one of us was to grow up to be a newspaper or movie critic/. (plan to integrate knowledge)</td>
</tr>
<tr>
<td>‘No Problem’</td>
<td>Claims in the article we didn’t understand very well included... /that Anti-Heat shirt and how it doesn’t attract any heat what-so-ever!/ Now /how can that be so if everything must have some sort of heat energy in it/. /What about the heat that your body produces, wouldn’t it eventually wear off on to this miracle shirt/? (actual integration of knowledge)</td>
</tr>
</tbody>
</table>

Individual comments are italicized and separated by slashes; in these examples, all comments within a response have the same reflection focus.
the coding of students’ focus in self-monitoring prompts. Studies 1 and 2 provided pilot data for the third study, which focused primarily on prompt responses.

In study 3, we divided students’ responses to the self-monitoring prompts into individual, independent ideas called comments. Each comment was characterized as focusing on actions, project activities, project ideas, or knowledge (see the categories in Table 1: in student examples in Table 1 and throughout this paper, only distracting spelling or punctuation errors have been changed). Comments coded as actions were typically ‘schoolish’ responses, focusing on school or social behaviors or very general project goals. Comments coded as project activities were goal-oriented but were specific to the particular project. Comments coded as project ideas were also specific to the project at hand but, focused on concepts or processes students were to learn (e.g., energy conversion, critiquing) rather than on logistics. Comments coded as knowledge could indicate a plan to think about knowledge or could indicate actual links to existing knowledge. These responses are grouped because both indicate a propensity toward knowledge integration. Responses of ‘no problem’ or the like were coded as not reflective.

We then assigned a set of overall characterizations to each response based on the proportion of comments in each response focusing on each type of reflection. Those proportions allow identification of the degree to which students focused on each aspect of reflection. We also counted the number of words and comments in the responses, to assess the degree of elaboration of the responses.

Results

What effects do the two types of prompts have on students’ reflection and knowledge integration? What are the strengths and weaknesses of each type of prompt? How do students respond to the prompts? This section will address these questions, presenting the results of each study.

Study 1: comparison of self-monitoring prompts and activity prompts

The first study compared self-monitoring prompts to activity prompts. One group received only two activity prompts, while the other group received seven self-monitoring prompts in addition to the activity prompts. This study was undertaken to identify whether students would benefit from the planning and reflection activities promoted by self-monitoring prompts, as compared with prompts that focused instead on the justifications of decisions. We evaluated students’ responses to the two types of prompts and rated their final designs.

The overall quality of the two groups’ 65 designs for ‘aliens on tour’ was the same. Although the groups who received only activity prompts had more time for their reports, they did not create better designs. While designs were of equal quality, explanations varied by prompt condition. The activity prompts were more successful at directly eliciting scientific ideas or conceptions than were the more general self-monitoring prompts, as we expected. In addition the students in the self-monitoring prompt condition gave fewer purely descriptive explanations and, were significantly more likely to use at least one scientific principle in their designs ($\chi^2 = 8.92, p < 0.05, df = 2$). A descriptive example, with no scientific principles, looks like this:
The first floor will be like a lobby. . . . The second floor is where the Kulebeings will stay. . . . On each side of the floor we will cover with a half inch layer of stucco. We will also [have] a carpet made of wool. For the walls we will use 8" of concrete blocks which is framed and lined with polystyrene boards which is then layered with half an inch of stucco. . . . The third floor is where the Equilibs will stay. Because of their adaptability the walls will be made of 8" of brick layered with half an inch of stucco. . . . [continues on in this vein, with more and more materials being used and layered together.] On the outside of the house we will cover with stucco and paint it yellow.

A principled (and more succinct) clothing design looks like this:

The clothing for the Sizzle Persons will be made of black wool and it will be tight against their bodies. The clothings should be rather thick. . . . The Kulebeings will also wear tight clothing in thick wool. The wool suits [for the Kulebeings] will be covered with cloth to reflect the light energy off of them. The wool will also be white. . . . The Kulebeings should have thick wool suits because it will help to keep the heat energy out of their bodies. . . . This [design] will keep the Kulebeings cold because wool is a good insulator and not much light energy is absorbed by the suits.

The second example augments description with principles to justify the decisions being made. The self-monitoring prompts elicited better explanations. Approximately 21% of students in the activity prompt condition applied no principles at all to their designs, compared to only 3% of the students in the self-monitoring prompt condition \( \chi^2 = 8.92, p < 0.05, df = 2 \).

Furthermore, twice as many students in the activity prompt condition (30%) used descriptions rather than scientific explanations (15% in the self-monitoring condition). In addition, 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 condition. Though these differences are not statistically significant due to the small numbers of projects involved, they do suggest the need for further research.

**Study 2: extension and replication of comparison**

In study 2 we equalized the time students spent on responding to prompts in each condition. One group received only self-monitoring prompts, one group received only activity prompts and, a third group served as a control. Study 2 also extended study 1 by investigating, in the context of a different project, the extent to which students integrated their understanding.

Altogether students created 60 projects. Overall completion varied by condition. Most of the students (78%) in the activity prompt condition completed all pieces of the project, such as writing guidelines for using evidence, as compared to 32% of the self-monitoring prompt group and 42% of the control group. A Fisher’s Exact test found that the activity prompt group was significantly more likely than the self-monitoring prompt group \( p < 0.002 \) and than the control group \( p < 0.04 \) to complete all the pieces of the project. Although we expected a difference in completion rates, the degree to which the conditions performed differently was unexpected (see figure 6).

Students in the self-monitoring prompt condition of study 2 were significantly more likely than those in the activity prompt condition to explain phenomena using a principle and one or more other types of cites, such as everyday experiences or laboratories done in class. This represents principled knowledge integration.
The following example demonstrates integration of a lab, a principle and, some real-life experiences:

Then we looked at claim two which was ‘Heat sources cause the temperature to go up’. We looked at the evidence ‘ovens heat up kitchens’. This evidence reminded us of the two pulsing labs that we did in class because in those labs the pulsar gave heat off to its surroundings just like the ovens gave heat off to the kitchens (their surroundings). The most convincing part of the evidence was the graph. The evidence would have supported your claim very well if you hadn’t left the oven door open after you took the cookies out. When you did that all the heat got out and because of that the temperature went up dramatically. It is true that the oven would have given off the heat eventually, but if you leave the oven door open the heat will heat up the kitchen faster. Also it is not common to leave the oven door open after taking cookies out.

In contrast, the activity prompt gave significantly more principle-only explanations (χ² = 7.83, df = 3, p < 0.05). Figure 7 shows the difference in principled knowledge integration of the two conditions. Studies 1 and 2 show that self-monitoring prompts encourage students to integrate their knowledge. In study 1, students who received self-monitoring prompts were more likely to cite at least one principle and, in study 2, the self-monitoring prompt group was more likely to link those principles to other ideas.

**Study 3: in-depth investigation of prompt response and reflection**

In study 3 we investigated the mechanism behind self-monitoring prompts. All students received 11 self-monitoring prompts, as well as a set of activity prompts. We analysed the reflection the self-monitoring prompts elicited (because our focus is on the effects of self-monitoring prompts, responses to the activity prompts were not included in the analysis for study 3).
Students created 44 projects, making a total of 484 self-monitoring prompt responses; students left less than 10% of the self-monitoring prompts unanswered. Students differed in the degree to which they elaborated the ideas in their responses. The average number of words in each response was 22.6 (excluding the sentence-starter prompts themselves). The corpus of data includes a total of 1030 comments. The average number of comments per response was 2.3. For example, an elaborated response is:

Claims in the article we didn't understand very well included... the claim that some materials are naturally cold. We disagree because the coldness or hotness of an object depends on the amount of heat energy an object contains.

This response connects a claim from the activity to a class principle. Some students also connect claims to their personal experience. A less-elaborated example is:

Claims in the article we didn’t understand very well included... the claim that some things are naturally cold.

While these students responded to the prompt, they did not elaborate. We correlated response elaboration with students’ project scores. Students who wrote lengthy responses to the checking our understanding prompts (prompts for monitoring) tended to do well on the project as a whole ($r = 0.39$, $p < .01$).

To analyse reflection, we look at comments made in response to the prompts. Comments addressed project activities (39%), project ideas (21%), knowledge (18%) and, actions (12%). A surprising 9% of the overall comments claimed no need for reflection. Less than 2% of the comments did not fit into the coding scheme delineated in table 1.

Not surprisingly, self-monitoring prompts with different orientations elicited different kinds of reflection. Responses to thinking ahead prompts mainly focused on activities (59%), knowledge (20%) and actions (16%). Reflection in response to checking our understanding prompts focused mainly on project ideas (55%), although 21% of the comments were in the unreflective ‘no problem’ category. Responses focused on project ideas correlated with high project scores ($r = .31$, $p < .05$). Project idea responses to checking our understanding prompts were highly related to project scores ($r = .30$, $p < .05$) and were predictive of the coherence of students’ ideas ($r = .31$, $p < .05$). This may account for the relationship between length of checking our understanding responses and project scores. Together these findings show that prompts can improve project success when students elaborate on the ideas in the project that they do not fully understand. In one example, one pair responded to a checking our understanding prompt this way:

Pieces of evidence we didn’t understand very well included... a lot of the science theories.

This pair would be less likely to develop a coherent understanding of the science ideas than would a pair who elaborated more on specific project ideas, for example:

Pieces of evidence we didn’t understand very well included... the chemical or ‘anti-heat’ shirt because they didn’t really explain about the shirt was made out of or evidence that the shirt actually worked. We also didn’t understand the small and large rooms one because it didn’t give their original temperature’s of the room and
their were three people in the small room and only one in the large room so that there was more body heat in the small room to begin with so that they should have the same amount of people in each room.

In addition, the unreflective or 'no problem' response is significantly negatively correlated with students' project scores \( r = -.40, p < .01 \), especially for checking our understanding prompts \( r = -.48, p < .001 \). This complacency interferes with project success. Unreflective responses were particularly predictive of poor overall critique quality \( r = -.30, p < .05 \).

Studies 1 and 2 indicate that self-monitoring prompts help many students integrate their knowledge. Study 3 shows that students who identify confusion benefit more from self-monitoring prompts than those who deny any difficulties.

**Discussion**

These results shed light on the design of learning environments as well as on the learning of science. We summarize design and learning study results separately although they complement each other.

**Design implications**

These studies show that prompts can play a variety of roles in learning environments, requiring that designers carefully craft the form and frequency of prompt experiences. Prompts can help students complete each element of an activity but may actually reinforce efficient step-by-step responses rather than the integrated understanding we desire (see figures 6 and 7). In essence, prompts can automate the process of following a set of experimental procedures without paying heed to the outcomes, findings, or anomalies that emerge. Many critics of science courses point to the experiments that students mindlessly complete. Prompts that move students along can contribute to this form of science course participation.

Prompts can also enable sophisticated knowledge integration when they encourage students to monitor their progress and identify new connections among ideas. When asked to check their understanding or think ahead, close to 80% of responses were supported by one or two connections. In contrast, when prompted to move along, only about 60% of the responses were supported by one or two connections (see figure 7).

These studies also demonstrate that students, as a group, need a mix of self-monitoring prompts since individuals use prompts in varied ways. Over 90% of the prompts elicited student responses but, these responses varied. Knowledge integration reflected in the discussions of project ideas (21%) and connections between the project and related knowledge (18%) accounted for about 40% of the responses made by students. Another 40% of the responses focused on project activities which required attention to the overall goal of completing a complex project. The remaining 20% of responses did not feature knowledge integration—indeed almost 10% of the responses asserted that reflection was not required.

The form of self-monitoring prompt also influenced responses. Among self-monitoring prompts, checking our understanding prompts elicited both the most discussion of project ideas (55%) and the most unreflective (21%) responses. In contrast, thinking ahead prompts almost always resulted in reflection but elicited more discussion of activities (59%) and almost no discussion of project ideas.
These findings underscore the importance of offering students a mix of opportunities for reflection. They also illustrate the importance of conducting design studies to refine instruction. This and other studies help clarify the nature of prompts that promote knowledge integration.

**Learning implications**

These investigations suggest that prompts can influence student learning. Activity prompts help students finish activities but do not necessarily help the students develop an integrated understanding. These prompts may lessen the cognitive load on students, by reminding them how to accomplish the activity. They guide the inquiry process and help students to walk through the activities step-by-step. These prompts may, however, encourage a piecemeal solution, by emphasizing each step rather than how the steps work together or how ideas could connect to one another.

Self-monitoring prompts encourage students to reflect on their own understanding. The self-monitoring prompts do not directly elicit integrated knowledge but, provide scaffolding to help students think about their goals for and progress on a project, topics on which students are not generally requested to think. These prompts begin to help students to engage in the knowledge integration processes like making links and restructuring ideas.

How do students decide to interpret invitations for reflection? All three studies indicate that students differ in their orientations toward reflection. Students interpret our criteria for productive reflection (mainly planning and monitoring) differently. From the choices they make we can infer their criteria for reflection. Students in study 3 who focused on project ideas ended up being the most successful on the project and, in particular, developed the most integrated understanding of the ideas.

When given prompts meant to encourage students to assess their understanding (the checking our understanding self-monitoring prompts), students often denied the need for reflection—fully 20% of students’ responses to these prompts assessed their understanding as perfect. These ‘cognitive economists’ (Linn et al. 1996) claim to understand all the ideas in a project and, ultimately demonstrate less successful critiques of evidence and claims than students who reflect. This is consistent with work by Chi and her colleagues who found that spontaneous high self-explainers were far more accurate in their assessments of their own understanding than were low self-explainers (Chi et al. 1989). Prompting students for self-explanations, while having overall positive effects, was not equally successful for all students (Chi et al. 1994).

**Conclusions**

How do these findings fit in to the scaffolded knowledge integration framework? Self-monitoring prompts let students make their own thinking visible and explicit, though we see that not all students take advantage of the opportunities given to them. By articulating their plans, thoughts and confusions, they are better able to note areas in which their own understanding is lacking and to engage in knowledge
integration. But by not articulating their ideas, they forego opportunities to integrate their knowledge. At the same time, the prompts model the act of reflecting, and help students learn to reflect autonomously.

Can designers use prompts to encourage reflection and knowledge integration? The design studies show that we can improve prompts so that more students reflect. Self-monitoring prompts succeed in encouraging reflection more than activity prompts, although prompting students to engage in all aspects of the inquiry process helps some students (see also, White and Frederiksen 1998). Iterative design of instruction offers the best prospects for encouraging knowledge integration. We hope our findings will motivate others to investigate the ways to use prompts in learning environments.

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References


