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# How Do Students' Views of Science Influence Knowledge Integration?

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## Abstract

This study characterized students' views of science as falling into three groups: static, mixed, and dynamic. Those who view science as static assert that science consists of a group of facts that are best memorized. Those who view science as dynamic believe that scientific ideas develop and change and that the best way to learn these ideas is to understand what they mean and how they are related. Students with mixed beliefs hold some static and some dynamic views. This study also examined the relationship between views of science and acquisition of integrated understanding of thermodynamics. We found that students with dynamic views acquired more integrated understanding than those with static views. Participants were 153 middle school students following the Computer as Lab Partner (CLP) curriculum. Students conducted both simulated and real-time experiments using an electronic notebook during the 12 weeks of instruction. Interventions encouraging students to integrate their experiences resulted in 89% of students successfully predicting the outcome of an everyday situation and 77% of students being able to succcessfully explain their prediction. We investigated how students preferred to integrate their experiences and found that some students preferred a concrete prototypic locus for integration while others preferred a more abstract principled locus of integration.

Do scientists ever disagree with each other? Will scientific principles found in classroom textbooks always be true? How do scientists verify new ideas? Which is better: to memorize facts or try to understand complicated material when learning science? Student answers to these questions reveal a great deal about their views of science, their strategies for learning science, and their accomplishments in science courses.

In this article we characterize the beliefs that students hold about science and about the learning of science material. We analyze the relationship between these beliefs and the integration of scientific knowledge in the domain of thermodynamics. Finally, we determine how students respond to concrete, as opposed to abstract, loci for knowledge integration and assess whether these preferences are related to beliefs about science.

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### *Beliefs about Science*

What do we mean by "student beliefs about science"? We sought first to characterize students' views of scientific knowledge and of scientists, and second to characterize their views about how science knowledge should be acquired.

What is a productive view of science knowledge? Historians of science report that science knowledge is socially constructed. The personalities of those involved have an impact on the pace of scientific advance as well as on the selection of the research agenda. This point is dramatically illustrated in the controversy between Galileo and the Catholic church (Brecht, 1980). Historians and philosophers of science also point out that science progresses by fits and starts, with either evolutionary or revolutionary changes in perspective (Kuhn, 1970). In addition, science knowledge is controversial, especially at the time of its discovery. Many current debates about treatments of AIDS, prediction of earthquakes, or extinction of dinosaurs illustrate the controversial nature of science. Finally, scientific knowledge is relevant to the lives and problems of individuals as well as societies. Fundamentally, historians, philosophers, and scientists agree that science is a dynamic enterprise involving conjecture, debate, verification, reanalysis, political influence, and a certain amount of good fortune.

The view of science communicated by historians and philosophers of science, as well as by many scientists themselves, differs markedly from the perspective one might develop from reading a typical science textbook (see also Reif & Larkin, 1991). Students could develop views of science that are quite divergent from those held by historians, philosophers, and expert scientists, because textbooks often communicate the results of this process, but give little indication of the process itself.

Besides studying beliefs about scientific advance, we also examine beliefs about learning science. These two types of beliefs are, of course, closely entwined, because conjectures about what one is learning are likely to influence the methods one uses for acquiring this knowledge. Many students report that they prefer to memorize scientific information rather than trying to understand it. Often the tactic of memorizing information is preferred because it is more efficient or better attuned to the assessment techniques found in many courses. Yet, if science is a dynamic, socially constructed set of ideas, then memorization is unlikely to yield understanding of how knowledge develops or of the nature of science itself.

How might beliefs about science develop? Elsewhere we have described development of scientific conceptions as moving from action knowledge to intuitive beliefs, and ultimately to scientific principles (Linn & Songer, in press a; Linn, Songer, Lewis, & Stern, in press). This framework can also be applied to the development of beliefs about science. Furthermore, other researchers have identified similar developmental progressions to explain how students come to understand scientific models (Grosslight, Unger, & Jay, 1991) and relationships among gears (Metz, 1991).

We describe knowledge acquisition as beginning with action and observation. We refer to the initial, unreflective ideas that students develop as "action knowledge." In the case of beliefs about science, action knowledge may include such beliefs as "science doesn't make sense," or "science is what the textbook says," or "science never changes."

We argue that action knowledge is combined using the process of reflective abstraction (Piaget, 1952) into "intuitive conceptions." These conceptions are the conjectures students make to explain observations or experiences. For example, students may develop intuitions such as "scientists use words that other people can't understand," or "scientists' theories apply to laboratory experiments, not everyday life." Students may develop contradictory intuitions. Thus, students may believe that scientists agree with each other and point to textbook statements along the lines of "scientists have found that matter is made up of particles." They may also believe that scientists disagree with each other and cite newspaper or television accounts of scientists arguing about cold fusion or treatments for cancer. These intuitive ideas may seem contradictory to an outside observer, yet understandable from the standpoint of the student. For example, a student may resolve this dilemma by saying that treatments for diseases are not part of "science." Similarly, in the area of thermodynamics, we find that students often hold separate beliefs about the nature of heating and the nature of cooling, believing, for example, that wrapping a cold drink in aluminum foil will keep it cold, and that an aluminium foil jacket would not keep someone warm. The development of scientific knowledge involves integrating beliefs about individual events, and recognizing that seemingly unrelated events are in fact explained by the same set of ideas.

We assert that effective instruction can help students sift through their intuitions and combine predictive intuitions into what we call "scientific principles." Principles are abstract general rules that explain what might be viewed as unrelated events. Examples include, "energy is conserved" or "objects in motion tend to remain in motion." Principles governing views of science might include "science proceeds by fits and starts" or "science is socially constructed."

In this article we analyze students' beliefs about science in terms of this developmental progression. We identify students in terms of whether they have action knowledge or intuitive beliefs about science. In addition, we characterize their intuitions as reflecting a dynamic or static view of science.

## *Knowledge Integration*

What do we mean by knowledge integration? We have argued that as students develop understanding of science, they organize action knowledge into intuitive beliefs and ultimately into principles. This process of organizing information into broader categories and into more widely applicable ideas results in knowledge integration. Our previous work indicates that expert teachers help students integrate such things as their understanding of heating with that of cooling (Linn & Songer, in press b). In addition, the process of knowledge integration involves distinguishing ideas that may seem similar at the onset to "make sense" of events. In thermodynamics, students often start with the notion that heat and temperature are the same phenomenon. Expert teachers can help them distinguish heat and temperature in order to develop a more predictive model of thermodynamics.

Songer (1989) reports on the effectiveness of instruction using a concrete integration aid. Her instruction helped students recognize that, for example, Styrofoam is a better insulator than metal, and that wool is better than metal as well. She then encouraged the students to organize these disparate pieces of knowledge along a continuum line with insulators at one end and conductors at the other. These comparisons were qualitative. Obviously, the thickness of the material or the conditions under which the material was applied could also influence the effectiveness of the material as an insulator or a conductor. Her training was very successful. Students who used the continuum line were better at understanding the nature of conduction and insulation than those who carried out experiments to investigate various materials and their effect on insulation but did not have the benefit of a continuum line as an integration aid (Songer, 1989).

Thus, by integration we mean the synthesizing of ideas into a cohesive and coordinated whole. Sometimes integration means recognizing that two seemingly different processes are really explained by the same underlying principles; at other times, in order to integrate a set of experiences, it may be necessary to differentiate concepts such as heat and temperature which had previously been seen as identical.

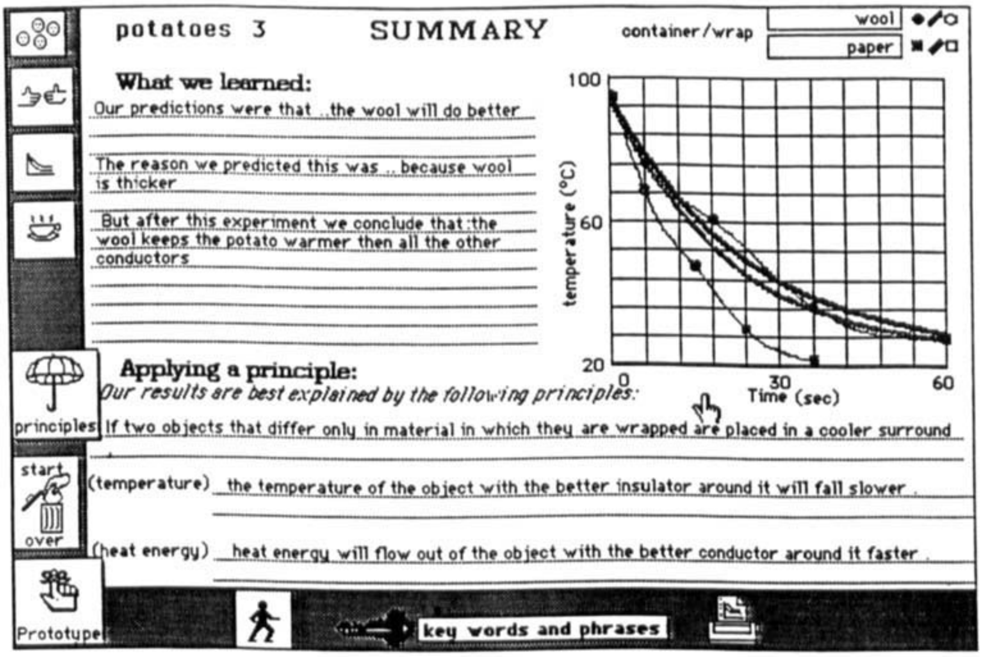
How do students develop integrated understanding? Songer's success with the continuum line suggests the importance of integration aids. In this study we explore two additional integration aids: pragmatic principles about thermodynamics, and prototypic thermodynamic events. By pragmatic principles we mean abstract principles that summarize thermodynamic experiments but are accessible to students. We distinguish pragmatic principles from expert principles and argue that pragmatic principles are more commonly qualitative than quantitative and more likely to be macroscopic than microscopic. In the case of thermodynamics, we (Linn et al., in press) identified pragmatic principles based on the heat-flow view of thermodynamics popular among scientists in the 1850s. Our version of the model includes the caveat that heat does not have mass, but in other respects is quite similar to a 1850s view of thermodynamics (see principles in Figure 1). In contrast, the view of thermodynamics based on molecular-kinetic theory is, in our estimation, abstract and microscopic, and therefore very difficult for eighth graders to integrate with their experiences and understandings. Our conjecture is that by offering students pragmatic models in eighth grade, we pave the way for their understanding of expert models when they return to this topic.

By prototypes, we mean familiar situations that illustrate a class of scientific events and for which most students have accurate predictions. For example, students can accurately predict what will happen if they stir hot liquid with a metal spoon and a wooden spoon. They point out that the metal spoon will get hot, but that a wooden spoon will remain cooler. Instruction can build on this prototypic experience to help students aggregate situations where different materials are in contact with the same heat source. The students are encouraged to recognize that the rate of heat flow depends on the material. Our use of prototypes to help students understand thermodynamics is consistent with Clement's (Clement, Brown, & Zietsman, 1989) call for bridging analogies and with Minstrell's (1982) benchmark experiments. Prototypes are more concrete than principles. Students whose understanding is quite disconnected, who have more action knowledge than intuitive beliefs, are likely to find prototypes more useful than principles. In contrast, students who already have well-developed intuitive beliefs are likely to benefit from scientific principles. Principles allow students to gain a more general and abstract view of the materal they are learning.

In this study, we contrast principles and prototypes as the locus for knowledge integration and report on students' reactions on these different forms of instruction. In addition, we relate students' efforts at knowledge integration to their beliefs about science.

### *Beliefs about Science and Knowledge Integration*

What is the relationship between beliefs about science and knowledge integration? Following our perspective on the development of scientific knowledge, it should be



**What we learned:**

Our predictions were that ..the wool will do better

The reason we predicted this was .. because wool is thicker

But after this experiment we conclude that :the wool keeps the potato warmer then all the other conductors

**Applying a principle:**

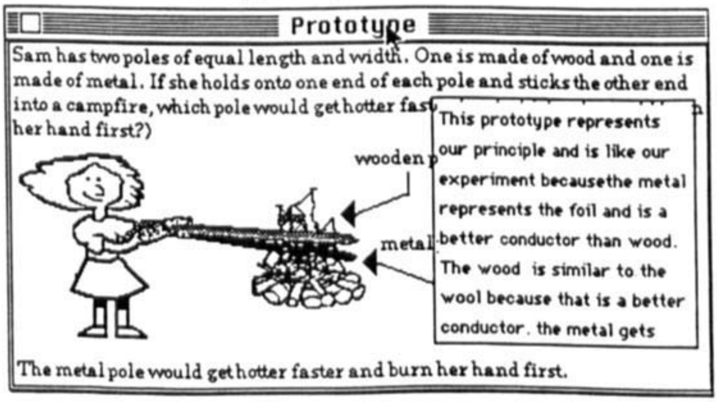
*Our results are best explained by the following principles:*

If two objects that differ only in material in which they are wrapped are placed in a cooler surround

(temperature) the temperature of the object with the better insulator around it will fall slower .

(heat energy) heat energy will flow out of the object with the better conductor around it faster .

When the Prototype button is pressed, a new window will open over the summary card with a prototype example such as the one shown below:



Sam has two poles of equal length and width. One is made of wood and one is made of metal. If she holds onto one end of each pole and sticks the other end into a campfire, which pole would get hotter fas

her hand first?)

This prototype represents our principle and is like our experiment becausethe metal represents the foil and is a better conductor than wood. The wood is similar to the wool because that is a better conductor. the metal gets

The metal pole would get hotter faster and burn her hand first.

*Figure 1.* Experiment summary card indicating principle and prototype integration.

clear that students may hold a range of intuitions about the nature of science as well as about scientific phenomenon. As students develop their understanding of science and of scientific phenomena, one goal is to integrate these views. In this study, we characterize consistencies between views of science and views of thermodynamics. In addition, we make conjectures concerning how these varied views might be integrated in productive and unproductive ways.

Students might integrate their views of science and of thermodynamics in an unproductive fashion. For example, if students believe that science is a collection of facts reported in textbooks, then memorizing those facts might be consistent with their view of science. In contrast, if students believe that science is progressing by fits and starts, and that scientists regularly reconsider ideas that have been developed in the past, then they might be inclined to understand scientific phenomena and to seek principles to explain their ideas. In addition, students who believe that science is dynamic might seek to integrate their diverse ideas and to build more predictive ideas about both science and thermodynamics.

Students' beliefs about science might empower them to participate in science courses and to integrate science knowledge. If students see scientists as grappling with complex ideas and trying to make sense of disparate information, they may feel empowered to engage in a similar process as they go about learning scientific ideas. In contrast, if they view scientists as quite different from themselves, they may decide to leave this grappling to scientists and wait until facts for them to memorize become available.

Views of science also have implications for application of scientific ideas to everyday life. If students view science as removed from themselves and their experiences, then they are unlikely to seek parallels between materials presented in their science classes and their own experiences. This decision to separate knowledge acquired in science class from experience outside of class ultimately has disastrous consequences for the integration of scientific knowledge. Unless students also draw on their own experiences and information that they gather in other contexts, they are unlikely to build a realistic or predictive conception of science, and they are very likely to decide that science is irrelevant or at least unimportant to their own learning.

### *Summary*

In summary, we conjecture that the development of scientific understanding proceeds from action knowledge, to intuitive beliefs, to scientific principles. A key feature of this development is the integration of ideas that may seem disparate or contradictory. In this article we characterize students' views of science as well as their views of thermodynamics, and examine the nature of the relationship that exists between these two forms of knowledge. We hypothesize that integrating views of science with knowledge of scientific phenomena will ultimately benefit students. For example, students who integrate their understanding of scientific phenomena across contexts such as school and everyday life may gain a more effective view of themselves as science learners and feel empowered to influence the direction science takes.

This study has three main goals. First, to characterize students' beliefs about the nature of science. Second, to assess the relationship between these beliefs and students' propensity to integrate knowledge of thermodynamics. Third, to examine the effectiveness of principles and prototypes as loci of knowledge integration and to determine which knowledge integration aid students prefer.

## Methods

### *Subjects*

The subjects of this study were 153 eighth graders enrolled in a one-semester physical science class in suburban northern California. The population was middle class, ethnically diverse, and contained a range of learning abilities. Students were assigned to one of six classes. All classes were taught by the same experienced mentor teacher.

### *CLP Curriculum*

Students followed the Computer as Lab Partner (CLP) curriculum developed by a team of researchers including the classroom teacher. The design of CLP curriculum activities was guided by current research in cognitive science and science education. CLP activities emphasize hands-on experiments using computers which are on line to real-time data-collection devices such as temperature-sensitive probes (for more information, see Friedler, Nachmias, & Linn, 1990; Linn & Songer, in press b). Although the curriculum and cognitive goals have been reformulated and improved over the 11 semesters of its use, the science content, basic experiments, teacher role, and student characteristics have remained largely the same. In addition, a continuous objective has been to encourage the development of integrated understanding of the concepts heat energy and temperature.

The 12 weeks of instruction featured experiments investigating a variety of concepts including heating and cooling, insulation and conduction, temperature equilibrium, specific heat, relative rates of heat flow when volume, initial temperature or surface area change, and the general differences between the concepts heat energy and temperature. Students work in groups of 3 or 4 at one of 8 computers. For each experiment, the students determined the design, predicted the outcome, explained their predictions, conducted the experiment, reconciled the outcome with their predictions, and integrated the result. Recently, the curriculum activities have been expanded to included simulations written in HyperCard for the Macintosh. Students used the simulated experiments to gather data on activities that are difficult or dangerous to conduct in the classroom. All experimental data, both real time and simulated, is organized in an on-line laboratory notebook (Linn et al., in press).

### *Integration Interventions*

Several activities were designed to encourage integration of thermodynamis concepts. These interventions fall into two categories: (a) the on-line integration interventions, which were identical for all students, and (b) the off-line integration interventions, which varied with class group. Integrations occurred at regular intervals during the semester.

### *On-Line Integration Interventions*

At the conclusion of each experiment, students created an on-line summary card which included all of the important experimental components: their predictions prior to experimentation, the experimental features tested, and the results achieved, including written conclusions and their data graph. As part of the activities, students needed to use the experiment information contained on the summary card to both construct a scientific principle which summarized the experiment, and integrate the result with a prototype example of the same concept. To aid construction of the scientific principle, students were given prompts and feedback which were scaffolded in complexity—

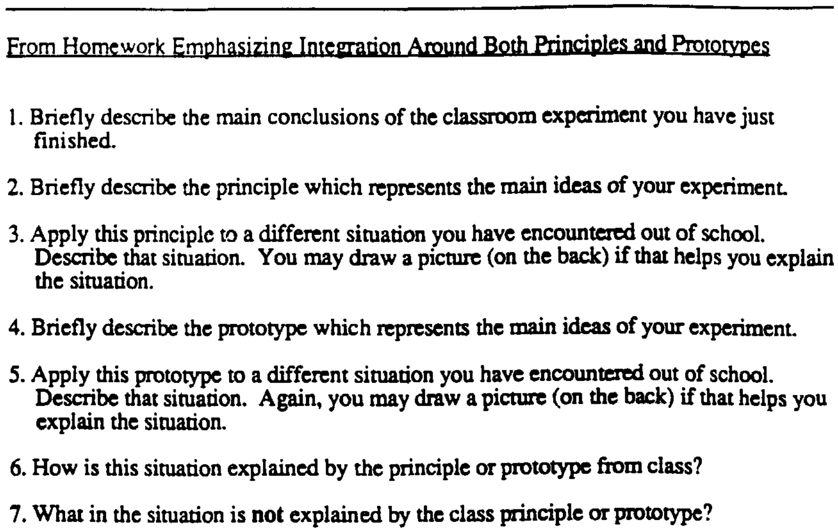
less general principles were accepted in early experiments, whereas only the most general principles were accepted in later experiments. Figure 1 displays a sample summary card containing a constructed principle and prototype.

Therefore, in this semester, unlike previous semesters, all students integrated heat and temperature concepts through the construction of principles and the justification of prototypes as a regular and frequent part of their curricular activities. This integration practice came through participation in the on-line activities associated with each experiments' summary card.

*Off-line integration interventions.* In addition to the on-line integration activities mentioned above, students participated in two off-line integration interventions. These were: "Related Experiment Worksheets," and "Integration Homework."

The Related Experiment Worksheets were used at four intervals throughout instruction, after each set of related experiments. For example, after all experiments concerning the effects of various insulating materials on the heating or cooling of liquids or solids, students were given an off-line worksheet which encouraged integration of the set of experiments. While all students were given instruction to integrate a set of experiments on each worksheet, the loci of integration emphasized varied by class: Two classes were instructed to integrate the experiments around principles, two around prototypes, and two around both principles and prototypes. Students were instructed to use the printouts of their experiment summary cards as background information.

The Integration Homework, given six times throughout the twelve weeks of instruction, required students to integrate one or two related experiments via the augmented loci of integration for their class (see Figure 2). For those classes emphasizing principles, students were asked to summarize the experiments, describe the principle constructed for that experiment set, and apply that principle to a new natural world situation which they felt was also explained by the class principle. Similarly, in those classes emphasizing



From Homework Emphasizing Integration Around Both Principles and Prototypes

1. Briefly describe the main conclusions of the classroom experiment you have just finished.
2. Briefly describe the principle which represents the main ideas of your experiment.
3. Apply this principle to a different situation you have encountered out of school. Describe that situation. You may draw a picture (on the back) if that helps you explain the situation.
4. Briefly describe the prototype which represents the main ideas of your experiment.
5. Apply this prototype to a different situation you have encountered out of school. Describe that situation. Again, you may draw a picture (on the back) if that helps you explain the situation.
6. How is this situation explained by the principle or prototype from class?
7. What in the situation is **not** explained by the class principle or prototype?

*Figure 2.* Sample integration homework questions.

prototypes, students summarized the experiments, described the prototype, and applied the prototype to a new situation. Students in the classes emphasizing both principles and prototypes for loci of integration did both of the activities as homework.

### *Experimental Design*

All students participated in 12 weeks of experimentation using the CLP curriculum activities on the eight Macintosh computers in the classroom. Prior to instruction, all students were given two pretest evaluations: the Views of Science Evaluation and the Heat and Temperature Evaluation. During the instruction, students performed real-time and simulated experiments, summarized them through the use of summary cards, and worked on the off-line integration interventions involving worksheets and homework. In addition, a small number of students were chosen at random for elaborative interviews to assess subject matter knowledge and integration skills. After instruction, two posttest evaluations were given: The Heat and Temperature Evaluation and an additional Principle and Prototype Integration Evaluation.

*The Views of Science Evaluation.* The Views of Science Evaluation was developed to determine the character and stability of students' beliefs about the nature of science. The test consisted of 21 short-answer and true-false items in the following areas: students beliefs about the nature of science and scientific knowledge, beliefs about the role or work of scientists, and beliefs about what it means to learn science, both inside and outside of classroom situations.

Designing items that elicit a range of valid responses has proven difficult. For several items responses varied little among all students, and for others, responses were not relevant to science beliefs. The nine items yielding valid, varied responses were used to determine student beliefs. Sample questions are included in Figure 3.

The data from the Views of Science Evaluation was used to create three science beliefs groups. Students who held the most productive beliefs about the nature of science were called the *dynamic beliefs* group. Of all the students, 15% were characterized as dynamic belief students. These students answered at least eight of the nine questions by indicating that they viewed science as understandable, interpretive, and integrated with many activities in the world around them. Those students who held the most unproductive beliefs were called the *static beliefs* group. We found that 21% of the students were characterized as static beliefs students. While all students expressed a few answers which implied productive beliefs, the static beliefs group demonstrated that for a majority of the nine questions analyzed, they largely viewed science knowledge as static, memorization intensive, and divorced from their everyday lives. The remaining group of students, called the *mixed beliefs* group, included the majority of students investigated. These students held some dynamic beliefs, some static beliefs, and some uninterpretable beliefs. Figure 3 demonstrates sample Views of Science Evaluation questions and characteristic responses for the static and dynamic beliefs students.

*The Heat and Temperature Evaluation.* The Heat and Temperature Evaluation was used to assess *isolated* thermodynamics knowledge and *integrated* themodynamics knowledge.

Isolated thermodynamics knowledge questions assessed students' ability to interpret single experiments or natural world situations and make predictions. Many questions required students to provide examples of natural world situations, classroom activities, or scientific principles to support their answers. For example:

| Question | Static Beliefs Students | Dynamic Beliefs Students |
|---|---|---|
| *When understanding new ideas, memorizing facts is better than trying to understand complicated material.* | "Yes, when I was in 7th grade and we had an exam coming up, I would memorize facts and I would get a good grade on the test."<br>"Yes, because if you try and understand complicated material there's a chance you won't understand it, with facts there's just facts." | "No, facts change."<br>"No, sometimes the facts don't give you all the information you need." |
| *Learning science for me is most like...* | "Memorizing words and facts. That is how I learn science, that is how I learn it best." | "Doing puzzles, because in science sometimes the pieces don't fit in your head. Sometimes you don't understand it. Sometimes you do. You just have to keep trying." |
| *The science I learn in school has little or nothing in common with my life outside of school.* | "Yes, when I drink orange juice, I don't break down the chemicals or minerals, I just drink it." | "No, sometimes I'll wonder why something in nature happened, and sometimes, with the little science I know, I can kind of make a guess." |
| *Describe something you learned in a science class which you could use to explain events outside of school.* | "Nothing." | "I have learned how to read weather charts, how to use computers, different types of animals, and how to come up with more than one explanation for what happened."<br>"If I found an animal or it's bones, I could probably identify it." |
| *Describe something you learned in a science class that you will never use to explain events outside of school.* | "Things about chemicals or animals." | "Nothing that I know of."<br>"There isn't one. Everything you learn is science is based on true life." |

*Figure 3.* Views of students holding static and dynamic beliefs.

Sam takes two identical pottery dishes filled with lasagna out of a hot oven and covers one with a pottery lid and the other with an identical metal lid.

After five minutes, what temperature will each pottery dish have? (a) Both the same; (b) one with pottery lid warmer; (c) one with metal lid warmer.

Choose yes or no for each of the following statements: (a) Heat energy will flow out of the dish with the pottery lid faster; (b) heat energy will flow out of the dish

> with the metal lid faster; (c) heat energy will flow out of both dishes at the same rate.
>
> What is the main reason for your answers?

Integrated thermodynamics knowledge questions assess students' abilities to synthesize the results from several experiments or activities. Students needed to go beyond the results of a given experiment or set of experiments in order to reach the higher levels of abstraction necessary for success with integrated thermodynamics questions. A sample question which emphasizes the distinction between the concepts heat energy and temperature is the following:

> In general, are heat energy and temperature the same or different? What is the main reason for your answer? Give an example which helps explain your answer.

*The Principle and Prototype Integration Evaluation.* The Principle and Prototype Evaluation assessed students' ability to integrate knowledge from classroom and natural world contexts around either scientific principles, prototypic examples, or both. Students were asked to apply and justify the use of scientific principles and prototypic examples to particular classroom and natural world situations. A sample principle and prototype question is as follows:

> You are preparing hot tea in a friend's kitchen. The kitchen sink contains two identical-looking faucets except one is made out of copper and the other is made out of a strong plastic of the same thickness. Your friend has the following question: When hot water is running out of both faucets and he wants to shut the water off, which faucet do you think will be LESS likely to burn your friend's hand?
> (a) Why do you think so?
> (b) Construct a principle which applies to this situation.
> (c) How is your principle similar to the situation?
> (d) Describe a prototype which applies to this situation.
> (e) How is your prototype similar to the situation?

This natural world situation resembled several classroom activities concerning insulation and conduction concepts that the students performed. In class, students conducted simulated experiments dealing with the rate of cooling of hot potatoes wrapped in materials with varying insulating abilities (aluminum foil, wool napkins, Saran wrap), the rate of heating of Coke cans wrapped in similar materials, and a real time experiment where they tested the rate of cooling of hot water in glass beakers and Styrofoam cups. As a part of the concluding summary card activities, students were asked to construct a principle and justify a prototype. Similarly, the Principle and Prototype Integration Evaluation asked students to construct principles and describe prototype situations. In both the classroom and evaluation activities, students were judged successful at principle construction if they could design principles which identified the relationship between the changing variable and the rate of heat energy gain or loss. Students were successful with prototypes if they could describe and defend a natural world situation which was different than the situation provided, but also identified the relationship between the changing variable and the change in heat energy.

## Results and Discussion

To characterize students' beliefs about science, we separated students into the static, mixed, and dynamic groups based on their responses to the Views of Science Evaluation. We then examined the performance of these groups on the various knowledge integration assessments. In addition, we examined whether the knowledge integration augmentations improved understanding. We also assessed students' preferences for prototypes or principles as the locus of knowledge integration.

### *Views of Science*

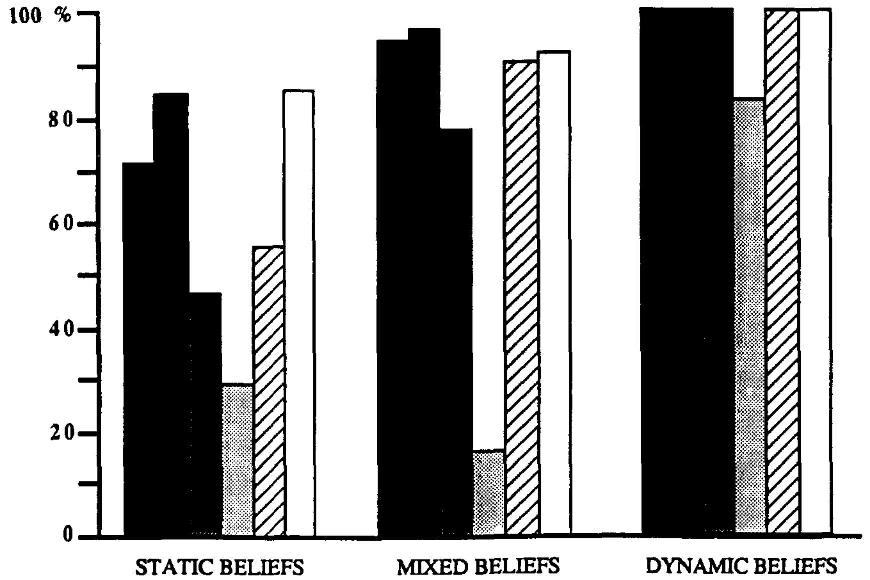
Only about 15% of these middle school students reported a dynamic view of science. In contrast, 21% reported static views, and the remaining 63% held mixed views. As shown in Figure 4, our criteria for static and dynamic views of science were relatively strict. Only students who consistently answered questions from a particular perspective were assigned to these groups. Most students ended up in the mixed beliefs group.

Students with dynamic views of science recognize that scientific knowledge is controversial. These students realize that scientists compare results and that scientists can look at the same experiment and reach different conclusions. Students in this group also believe that scientists use evidence to resolve controversy. As would be expected, students in this group extend their view of the dynamic nature of science to their perspective on science learning, reporting that science principles in textbooks may not be true, and that understanding new ideas is preferable to memorizing facts when trying to learn complicated material. These students have a cohesive and realistic view of science. They are likely to understand instruction that stresses that science is socially constructed. We anticipate that, in addition, these students recognize the possibility that if they were to participate in science, they could have an impact on the direction of scientific advance.

In contrast, the 21% of students who hold static beliefs about the nature of science believe that scientists do not expect principles to explain a broad array of events. These students deny the integrative function of scientific knowledge acquisition. Furthermore, they cannot differentiate between established scientific ideas and current scientific controversies. In addition, these students often believe that all scientific principles in textbooks will always be true, and they view science as best learned by memorizing facts rather than attempting to understand complicated material. Thus, these students see science as essentially static and unchanging. They see scientists as simply adding to the store of knowledge rather than debating alternative perspectives or trying to group many events under a single principle.

How do these belief groups reflect our perspective on the development of scientific knowledge? The small number of students who hold dynamic beliefs about the nature of science have an intuitive view of science that is consistent with that of experts. These students have integrated their view of science with their ideas about learning science. Furthermore, their perspectives of scientists are consistent across questions about scientific knowledge and scientific behavior. These students recognize the integrative function of scientific principles.

In contrast, students with static beliefs about the nature of science appear to hold quite a few beliefs that are at the level of action knowledge. We suspect that these beliefs stem from experience with classroom science learning. These students' knowledge



*Students chose Yes or No in response to the following statements:*

| | Beliefs about scientists: | Recorded Answer |
|---|---|---|
| ■ | Scientists can look at the same experiment and reach different conclusions. | Yes |
| ■ | Scientists expect one principle to explain many scientific events. | Yes |
| ■ | Scientists disagree about explanations for scientific events. | Yes |
| ░ | To verify their findings, scientists compare their results to those of others. | Yes |
| | **Beliefs about learning science:** | |
| ▨ | The science principles in the textbooks will always be true. | No |
| □ | When understanding new ideas, memorizing facts is better than trying to understand complicated material. | No |

*Figure 4.* Responses to beliefs quiz questions by beliefs group.

reflects primarily a rather superficial perspective on science learning. These views lack integration with students' everyday experiences. For example, students' static beliefs are incompatible with the notion that scientists at one point believed that the world was flat, or with debates among scientists concerning the explanations for earthquakes or the extinction of dinosaurs.

Students with mixed beliefs have a variety of ideas about the nature of science and about the learning of science. This is consistent with our findings of mixed beliefs in other domains. Our examination of students' views of thermodynamics, for example, reveals that students often hold unintegrated views of heating and cooling. Thus, students may assert that wool is a good material for keeping people warm, but is not able to keep ice cream cold. Students may draw on their experiences outside of science class to justify some of their intuitions, while drawing on explanations from science textbooks that report the results of the scientific process rather than describing the nature of scientific events to justify other intuitions.

In summary, most students have unintegrated views about the nature of science. Some of those views may stem from a superficial interpretation of their science textbooks. Students who view the information in a science textbook as static are unlikely to examine the process that generated the information. Students with dynamic views of science draw on their understanding of the process of scientific advance. These students generally hold more productive views about the learning of science than students with static views of science. Should science educators help students develop a more dynamic view of science? Would such a view facilitate learning of scientific concepts? To partially answer this question we examine the relationship between beliefs about science and knowledge integration.

### *Knowledge Integration*

To investigate the relationship between views of science and the integration of thermodynamics knowledge, we summarized performance on the knowledge integration assessments and compared the performance of the three beliefs groups. As discussed in the methods section, instruction featured the CLP curriculum reformulated to emphasize knowledge integration. Students were encouraged to integrate their knowledge around pragmatic principles and prototypic events during on-line integration activities associated with each experiment. All students used the pragmatic principles and the prototypic events to summarize the experiments that they conducted in class (see Figure 1). In addition, during off-line integration activities and homework assignments, some students integrated their knowledge around principles, others used prototypes, and a third group used both principles and prototypes. In this section, we look at knowledge integration independent of the off-line integration augmentations. The following section will examine the effect of varying integration augmentations on student knowledge integration.

We examined three aspects of learning from the Computer as Lab Partner curriculum. First, we looked at students' understanding of thermodynamics ideas in isolation from each other. Second, we looked at two forms of knowledge integration: first, integration of information around principles and prototypes, and second, integration of heat energy and temperature.

All students made substantial gains in their understanding of general concepts in thermodynamics as shown in Table 1. In particular, after instruction, 89% of the students were successful in predicting the outcome of an everyday situation similar to an experiment conducted in class. Also, 77% of the students were successful at explaining the reasoning behind their prediction.

Overall, 60% of the students successfully used principles and prototypes introduced in the study of thermodynamics to integrate their knowledge from different contexts (Table 1). When integration of information around principles and prototypes was analyzed by students in beliefs groups, students in the static beliefs group were somewhat less successful than students in the dynamic beliefs group. Comparing static beliefs students to dynamic beliefs students for the five principle/prototype integration items, the effect size was 0.45, which shows a trend towards greater integration by dynamic beliefs students; however this result was not statistically significant ($df = 2$, $n = 137$, $p < 0.21$).

Table 1
*Progress on Knowledge Integration*

| Question type | Correct responses ($n$ = 153) Percent | Correct responses ($n$ = 153) Standard deviation |
|---|---|---|
| Predict outcome for everyday situation | 89.0 | 0.31 |
| Explain prediction for everyday situation | 77.6 | 0.42 |
| Construct a principle to explain class of everyday situations | 57.7 | 0.50 |
| Apply a principle to a new situation | 59.6 | 0.50 |
| Create a prototype to explain class of new situations | 50.9 | 0.50 |
| Apply a prototype to a new situation | 60.2 | 0.49 |

Finally, all students made substantial gains in their understanding of the distinction between heat energy and temperature. The pretest-posttest effect size was 0.4 (Wilcoxson Signed-Ranks Test, $p < 0.05$). Students on the posttest ($m$ = 0.31, $sd$ = 0.46) were significantly more successful at heat and temperature integration than students on the pretest ($m$ = 0.16, $sd$ = 0.37). In addition, on the heat energy and temperature interpretation item, those with dynamic beliefs were significantly more successful ($m$ = 0.59, $sd$ = 0.50) than those with static beliefs ($m$ = 0.13, $sd$ = 0.35). The effect size was 1.09 (see Figure 5). Furthermore, on the five integration items combined, the same relationship held with dynamic ($m$ = 4.15, $sd$ = 1.05) exceeding static ($m$ = 3.03, $sd$ = 1.45) by an effect size of 0.92. An ANOVA comparing the three belief groups yielded a significant effect as well ($df$ = 2.143, $p < 0.01$).

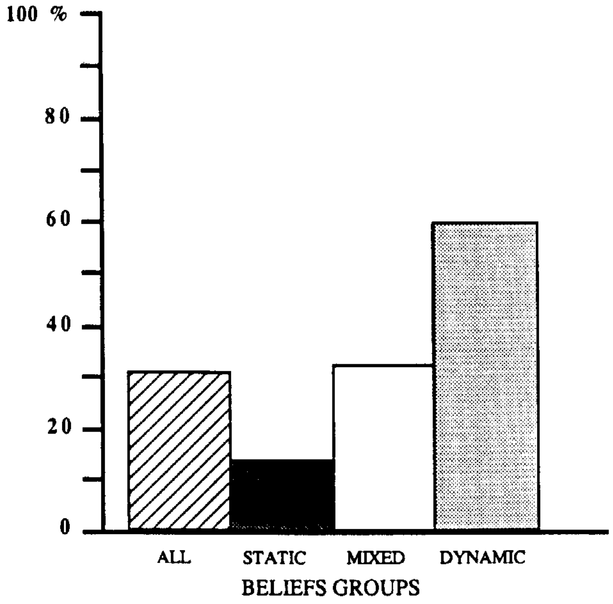
Thus, as anticipated, there is a relationship between beliefs about the nature of science and students' propensity to integrate the knowledge presented in the CLP curriculum. Students with dynamic beliefs about science were more likely to develop integrated understanding of heat energy and temperature than students with static beliefs.

For students with dynamic beliefs about the nature of science, we see an integration and cohesiveness between their views of science learning and the kinds of material that they master. These students believe that the best way to learn science is to understand it and they recognize that scientists expect one principle to explain many scientific events. Their understanding of science is consistent with this perspective. They are more likely to have integrated views of heat energy and temperature, and to attempt to organize the material presented to them around principles and prototypes.

### *Consistency with Other Investigations*

This finding extends the work of Songer (1989). Songer found that students with predictive beliefs about the nature of science performed better on integration than those with unpredictive beliefs. She also reports that type of belief was not associated with accuracy of recall of heat and temperature information.

Thus, in both the Songer investigation and in this investigation there was no relationship between beliefs about science and recall of heat and temperature information. These findings are consistent with the view that students who hold static views of science and memorize information will do just as well on tests that do not require



*Question:* Explain why heat energy and temperature are the same or different. Give an example which helps illustrate your answer.

(one way ANOVA, $p \leq .002$)

*Figure 5.* Performance on heat and temperature integration question by beliefs groups.

knowledge integration as will students who are attempting to develop integrated understanding. In contrast, when integrated understanding is emphasized in the curriculum and required on the assessments, then students with dynamic views of science will be more successful than students with static views.

### *Locus of Integration: Principles and Prototypes*

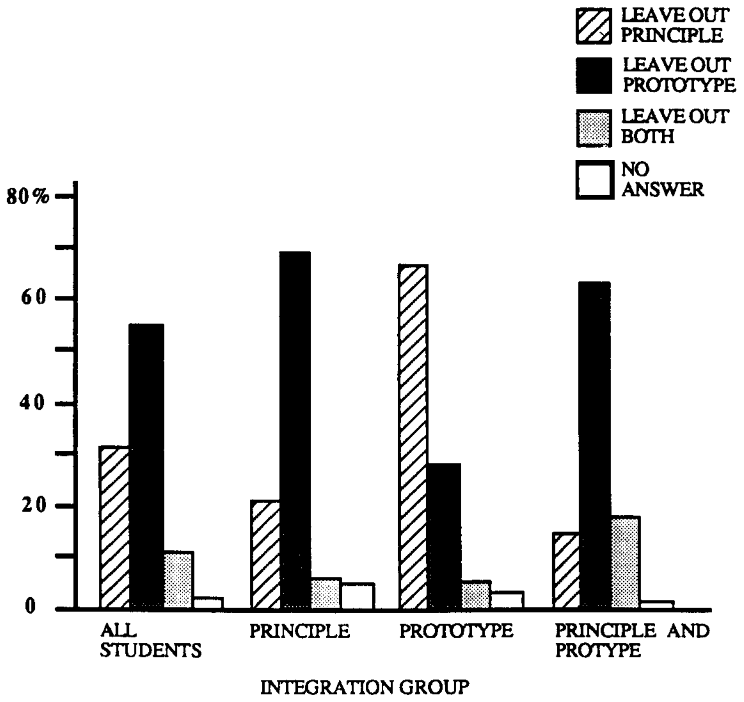
A third goal of this investigation was to examine the effectiveness varying the locus of integration for related experiment worksheets and integration homework. After every two–three experiments, students completed the off-line integration homework activities that emphasized either principles, prototypes, or both, as the locus of integration. In addition, students practiced organizing these related experiments around principles, prototypes, or both in off-line related experiment worksheets. Two classes were encouraged to integrate their experience around principles, two classes focused on prototypes, and two classes used both principles and prototypes.

These integration activities were very successful regardless of which loci of integration was emphasized. Students completed the assignments and reported enjoying the activities.

In general, students liked all of the approaches. There were no differences between students assigned to the principles group, the prototypes group, or the principles-plus-prototypes group on subject-matter knowledge acquisition or on the ability to integrate information about thermodynamics. This finding is not really very surprising given the limited nature of the off-line activities as well as the fact that all students were exposed to principles and prototypes during regular class activities.

We had conjectured that prototypes would be more appropriate for students whose knowledge of thermodynamics was primarily at the action level, whereas principles would be more suited to students who had intuitive beliefs about thermodynamics. To gain insight into this conjecture, we asked students to indicate which of the integration loci they preferred. The results of this survey are reported in Figure 6.

Students, in general, preferred principles over prototypes. However, students whose off-line integration activities primarily involved prototypes were far more enthusiastic about prototypes than were other students. Essentially, when asked whether they would eliminate principles or prototypes from future class activities, 68% of the



*Question*: If for next year's class we needed to leave out some parts of the materials used in this class, which one of those listed would you suggest we drop?

(one way ANOVA, $p \leq .0001$)

*Figure 6.* Preferences for principles and prototypes by knowledge integration group.

students who used principles to integrate their experiences would eliminate prototypes, whereas 66% of the students who used prototypes to integrate their experiences would eliminate principles. To clarify these results, we interviewed students and asked them why they preferred principles or prototypes for knowledge integration. Students favoring prototypes frequently indicated that the vocabulary in the principles was too abstract and difficult, whereas students favoring principles over prototypes frequently stressed that the principles were more general and useful.

When asked to explain why they recommended leaving principles out of the curriculum in the future, many students focused on the concreteness of prototypes. Examples include:

> Student (S1): I think the prototype is a little better.
>
> Interviewer (I): Why do you think so?
>
> S1: It is something you can relate to.
>
> I: What do you mean by 'relate to'?
>
> S1: Like, there is different ones where they put something on fire, wood, and metal and you can understand why you would heat up certain things from past experiences.
>
> I: So you kind of know something like that from outside of science class?
>
> S1: Yes.
>
> I: Okay. So, how was that different from what the principles do?
>
> S1: Well, some people might not understand . . . it just has some words that some people might not understand the words but they may understand the idea of it.
>
> I: So there is some words in there that were kind of confusing or what do you mean by they understood the idea?
>
> S1: They could understand the concept of it but not how to word it.

Other students preferred prototypes because they found the concrete examples particularly illuminating. They responded, for example:

> I: . . . Can you think about which one [principle or prototype] you know, if you had plenty of time, you might like to keep?
>
> S2: Prototype, because it's fun.
>
> I: Okay, good. So it's more fun. How about what helps you learn more? Either of them help you understand the experiment any more?
>
> S2: Prototype does.

I: Okay. What is it about the prototype that helps you understand more?

S2: When you're creating something [constructing the principle] it's kind of hard to get the actual process of how it works, but if you're actually doing it, it's a lot easier, you can see how it's been done and why.

I: So you mean the prototype is talking about something you can actually do?

S2: Uh huh. You know, you can be there to see what happened.

(later in same interview)

I: . . . Okay. So then, if this [prototype] is the whole thing, what is missing from the principle?

S2: Um . . . probably just being right there and seeing this one in depth. You can be right there. That [the principle] just tells you the main facts.

I: Okay, so the principle is just talking about facts, whereas the prototype gives you what?

S2: Everything.

Students who preferred principles over prototypes emphasized that the principles were clear and concise statements with broad explanatory power saying, for example:

S3: I think you should drop the prototype because most of the time, you just finished the lab, you know pretty much about it, except the principle, you have to construct then, you have to figure out which one is right and which one is wrong and how, and once you get that, then you have plan to a prototype which you already know, which is irrelevant because reiterating what you learn.

I: It's not giving you any new information?

S3: No, not really.

I: What does the principle do?

S3: It makes you think, in what situations it will work, well, a conductor will rise or fall more rapidly, but if you just put down fall, what about rise, it makes you think more, more universal. Prototypes just makes you think of instances and what is similar.

I: Can you say more about what you mean when you say that it [a principle] makes you think more?

S3: When you first decide what to write down or choose for the principle, there is so many choices and you have to think of what is universal because you think of, if you think that heat will fall, then you will think that it will fall faster or slower, then it says it will rise or fall then you think, well, maybe

> we'll do the same when it starts cold and goes to room temp. So maybe you think, "Hey, maybe rise or fall in any condition . . ." and you just think about other variables besides the one you are working on.

Others who preferred principles talked about the usefulness of principles for making predictions:

> S4: And a principle, I think is more important.
>
> I: Why?
>
> S4: And also principle refers to everything, prototype also goes under principle.
>
> I: So you can use the principles to talk about the prototypes too?
>
> S4: Yes.
>
> I: How does that make principles better?
>
> S4: When I do experiments I look at the principle a lot because I think it helps me understand experiments more and how to predict and what it's all about and what we are trying to find. If I look at prototype, it explains the situation and it explains what we are trying to look and what is wrong but it doesn't tell me exactly why or I don't know how to explain it. But the principle just tells you what it's all about and it explains everything.

These results suggest that whereas most students prefer principles for integrating their knowledge, there are students who find prototypes to be preferable. Furthermore, students may need considerable experience using prototypes before they fully recognize the advantages of these prototypes. Only those students who had augmented experience using prototypes to integrate their understanding recognize the value of prototypes for their own learning.

These findings provide insight both into the effectiveness of knowledge integration aids and students' knowledge of their own integration process. As can be seen, many students indicate they prefer principles over prototypes for integrating their knowledge; however, they may learn more by using prototypes than principles. At least for students in the prototype off-line integration condition, there was a gain in the realization of the importance of prototypes for knowledge integration. Instruction needs to help students both understand prototypes and recognize how to use prototypes to organize their knowledge. Students whose understanding of scientific phenomena is quite concrete may need help in integrating prototypes with their concrete knowledge in order to reach broader views of the scientific domain.

These results also demonstrate the advantages of using alternative integration aids for increasing student understanding of scientific phenomena. Some students preferred principles, whereas others found prototypes most effective. Overall, it was difficult to distinguish the effects of principles from the effects of prototypes. However, for individual students it was quite apparent that principles helped some, while prototypes helped others. The constructive process is an idiosyncratic one. Providing students with options within the learning environment is clearly advantageous and most likely to foster construction of understanding across a broad range of learners in complex domain such as thermodynamics.

## Conclusions and Implications

These results strongly suggest that students' beliefs about science are important and complement the development of thermodynamics knowledge. These studies also underscore the importance of focusing specifically on knowledge integration in helping students understand scientific phenomena. Students with predictive beliefs about science develop integrated knowledge. At the same time the process of integrating knowledge illustrates the complex process of scientific advance. Students may not integrate material presented in science classes if they believe that science consists of isolated principles. In addition, students may not develop a view of science consistent with historical evidence if science is presented to them as a collection of fairly unrelated facts and ideas. Thus, students are likely to gain a more integrated understanding of science if their courses emphasize both knowledge integration and knowledge about the nature of science. Ultimately the goal is to help students integrate their beliefs about science with their understanding of scientific phenomena. Only with this view can students appreciate that the development of scientific knowledge results from the activities of those in science.

This study demonstrates the advantage of explicit emphasis on integrated understanding. Songer (1989) demonstrates the effectiveness of the continuum line for helping students to integrate their understanding of insulation and conduction. This study augments and extends that investigation to demonstrate that principles and prototypes are suitable loci for the integration of groups of experiments in thermodynamics. This study also suggests that offering students a range of loci for integrating their understanding is advantageous, because for some students, principles would be too abstract, and for others, prototypes would be too narrow.

### *Goals for Science Instruction*

This study illustrates the danger of focusing science instruction too narrowly on facts or isolated pieces of scientific knowledge. Students rarely spontaneously integrate information presented in isolation. Instruction needs to focus students on constructing integrated understanding and support them in the process of developing these integrations. In order for students to move beyond isolated ideas and into a more predictive and productive understanding of science, intervention is needed. Early versions of the computer as lab partner curriculum did not foster sufficient knowledge integration and students were unable to organize their knowledge around principles and prototypes (Friedler et al., 1990; Linn & Songer, in press b). Instruction specifically focusing on integration was successful. This instruction supported students in their efforts to construct robust and cohesive views of thermodynamics. In addition, analysis of student learning under these conditions illustrated that dynamic beliefs about science were associated with more integrated understanding. Presumably, further augmentation of the curriculum to specifically emphasize the integration between views of science and views of thermodynamics would have even greater benefits for students. Such approaches are described by Duschl and Gitomer (1991).

### *Integration with Other Investigations*

These investigations coincide with findings from other reseachers and serve to augment and integrate previous investigations. Many researchers report that students have unproductive beliefs of science. Schoenfeld (1983) notes that students learning mathematics often report that the main idea is to memorize the algorithms and procedures rather than to try to make sense of the problems or the results of their problem-solving efforts. Schoenfeld also reports that students with more productive views of mathematics are more likely to make sense of mathematical problems and to report reasonable solutions. Students who lack this view of mathematics often give answers to problems that make no sense, suggesting for example that to transport a group of individuals you would need "three buses remainder six" or that the amount of wood needed to satisfy a set of constraints is "minus six" feet. Schoenfeld calls on mathematics educators to help students make sense of mathematics learning rather than allowing them to memorize mindless algorithms.

Novak and his colleagues have focused on knowledge integration from the perspective of having students draw concept maps. These investigators report that students often represent their knowledge as isolated and incohesive. Novak calls on teachers to review these maps and to work with students to help them recognize how information can be integrated (Novak, Gowin, & Johannsen, 1983). Schommer (1990) reports similar relationships by assessing students' beliefs about the nature of reading and their performance on reading comprehension tasks. Students who believe that comprehension is at the level of words or sentences are less likely to make sense of written communication.

Taken together, these investigations suggest the importance of helping students (and teachers) understand the processes under which knowledge is generated as well as the results of those processes. Unless students look jointly at knowledge generation and the outcomes of the knowledge generation process, they are unlikely to develop an integrated, productive understanding of science or of science concepts. Thus we call on educators, curriculum designers, researchers, and textbook writers to design materials that help students construct integrated understanding in a broad range of domains. We note, for example, that the Harvard Project physics curriculum emphasized a historical perspective on knowledge generation. Students responded favorably to this approach, yet it has not received widespread acceptance in textbooks and is rarely found in materials for mathematics and other domains.

Often we hear that historical examples about the process of scientific advance are left out of science courses because there simply is not enough "instructional time" to cover everything (Eylon & Linn, 1988; Linn, 1987). We believe that this perspective is wrong headed. Morrison (Apelman, Hawkins, & Morrison, 1985) has argued that "less is more." Unless students have sufficient opportunity to understand the nature of the knowledge generation process, they are unlikely to become participants in this process in the future and may instead believe that science knowledge is irrelevant to their own lives and to the lives of others like them.

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