Chapter 7: The Role of Students' Beliefs about Science and Learning

Introduction and Rationale

In the previous chapters I reviewed the gross effects of prompts and showed the kinds of reflection students engage in as a result of prompting. But how do individual students differ in their performance and reflection? One influence on students' knowledge integration may be their epistemological beliefs about science as a field and about themselves and their own learning.

The goals of this chapter are to identify and describe different dimensions of students' beliefs about both the nature of science and the nature of science learning, determine how those dimensions relate to one another and to student reflection and performance, investigate how beliefs change over time, and compare the beliefs of girls and boys.

The word "beliefs" here does not refer to students' conceptual understanding of science topics, but rather to their ideas about what science is like as a field, what counts as science, and how one does science. Furthermore, my definition of "beliefs" involves a focus on students' beliefs about learning rather than about knowledge (see Hofer & Pintrich, 1997, for a discussion of this issue.)

Research identifies a relationship between students' beliefs about science and their propensity to integrate their knowledge, or to build a cohesive understanding rather than a piecemeal one (Linn & Songer, 1993; Songer & Linn, 1991). Students' beliefs are related to their long-term progress in addition to their short-term performance in science class (Eylon & Linn, in press). Similar relationships have been identified between students' beliefs about learning and their performance in school (Schommer, 1990, 1993). Students' beliefs about knowledge and learning (within the domain of physics) may explain the range of performance of physics novices (Hammer, 1994). One rationale for the investigation of students' epistemological beliefs, then, is provided by the link often made between 'believing' and 'learning.' Specifically, I anticipate that students' beliefs can be used to identify instruction more appropriate to their individual needs.

Methods

This section presents the methods specific to the task of investigating students' beliefs. Because this analysis is fairly different from the ones discussed in Chapters 5 and 6, I include a substantial amount of background information here, as well as discussing the methods themselves.

Data Sources

Methods for studying epistemological beliefs are somewhat controversial. I provide the background of and rationale for the data sources I employed in this study, in addition to discussing the data sources themselves.
Data sources for this aspect of the study include, first, pre- and post-tests to assess students' beliefs. An identical assessment was given at the beginning and end of the course. (For simplicity, these beliefs assessments are referred to as the "pre-test" and "post-test" throughout the rest of the chapter. The subject matter post-test is referred to as the final exam.) As mentioned in Chapter 4, the assessment was administered online, using a series of Web forms. Students typed their responses to the 19 questions, which represented a mix of multiple choice and free response questions. The scoring of these assessments is discussed below.

Furthermore, 25 students were interviewed about their epistemological beliefs, as described in Chapter 4. Nine of these interviews provide qualitative data for the beliefs aspect of this study, with the nine students representing a wide range of initial beliefs.

The dimensions presented in Table 2–1 in Chapter 2 were originally investigated through an in-depth case study analysis of three students using a written instrument and a series of interviews to assess beliefs. That study investigated students' beliefs in the areas of the nature of science and the nature of learning, and linked those beliefs to their ability and propensity for giving scientific explanations. I found that students differed considerably in their beliefs about science and science learning, and that while "productive" beliefs sometimes co-occurred, this was not always the case. For a more complete discussion of this work, see Davis (1994).

Case studies allow us to describe the beliefs of small numbers of students, but do not allow us to assess the beliefs of all students in a class. Written assessments provide a more pragmatic approach. The current research uses an assessment instrument pioneered by Songer and Linn (1991; Linn & Songer, 1993) in the CLP classroom. A version of this tool was used in the Davis (1994) study, as well. The tool has benefited significantly over the years from continual trial and refinement; some questions have remained constant and others have changed or even been eliminated altogether. The version of the beliefs test used in the current research, for example, does not contain any items on parsimony (Linn and Songer's most troublesome category) but adds new items on students' motivations for learning.

Pragmatic aspects of the test have changed over the years, as well. For example, the survey given in the spring of 1992 contained 29 multiple choice or check-off items and 22 free response questions. Seven semesters later, the test included 49 multiple choice or check-off questions and 11 free response items. This evolution away from written responses has come about in part because of the current move toward the goal of being able to code students' beliefs rapidly rather than waiting weeks for the results. Another benefit of the larger proportion of multiple choice questions is that the amount of data available on any given student is increased.

One concern, of course, is that the multiple choice questions might not accurately represent students' beliefs. While a full analysis of this issue has not been attempted in the current study, exploratory investigations in this study and others indicate that multiple choice responses do provide a reasonably accurate depiction of students' self-reported beliefs. The current analysis uses answers to the multiple choice items as the primary data source, supplemented by answers to free response questions on the survey and interviews done with students. The decision to favor (relatively) objective data over rich data in this analysis is a conscious one. Interviews and observations can be flawed because they are, by their very nature, subjective. A non-intrusive tool like the survey used here also allows quick
assessment of students' beliefs. One implicit goal of this analysis is to explore the possibility of using epistemological data collected in real-time as a basis for decisions about students' experiences in class.

Of course, our ability to draw conclusions about students' beliefs is constrained not only by our ability to identify particular beliefs and a student's ability to articulate those beliefs in the first place, but also by the degree to which students' self-reports match their actions. Self-report is the mode chosen here. The claim is not made that students' actions and reports match identically. Instead, claims are made about the ways that self-reported beliefs (whether practiced or not) relate to other self-reported beliefs and to classroom performance. An implicit assumption is that for most students, self-reported beliefs are quite similar to the student's true beliefs. Others recommend instead assessing students' beliefs in the context of problem solving (e.g., Driver, Leach, Millar, & Scott, 1996; Hammer, 1994).

Outcome Measures

Outcome measures include, of course, assessment of students' beliefs about science and learning science, as well as the learning and performance measures employed in the analyses in previous chapters.

Dimensions of Students' Beliefs

As with the data sources, I provide first a rationale for the outcome measures used for assessing students' beliefs, and then discuss in some detail how those dimensions of beliefs are coded.

Rationale for Dimensions

Students' views of the nature of science are broken into two dimensions: the process of scientific inquiry and the relevance of science to students' lives. While other interesting aspects of students' beliefs systems certainly exist, these are particularly relevant to an investigation of middle school students.

Students' views of the process of science fall along a continuum of (borrowing terminology from Songer and Linn [1991]) 'static' to 'dynamic.' A student with a static view of the process of science sees science as a collection of unchanging facts and that scientists somehow arrive at the "truth." A student with a dynamic view, on the other hand, sees it as a changing field in which decisions are made on the basis of evidence and conjecture.

Views of the use of science fall along a continuum of 'irrelevant' to 'relevant.' Students who see science as irrelevant do not see what they learn in science as applying to their lives, whereas a student with a 'relevant' view sees applications of science in everyday life.

Beliefs about the nature of learning are broken into several dimensions, including strategy, autonomy, and goal. Again, while other aspects of students' beliefs may be interesting—for example, the level of activity or passivity students view as appropriate for learning science—the dimensions discussed here represent facets of middle school students' beliefs that are both measurable and meaningful.
Students' beliefs about appropriate strategies for learning science can range from memorizing facts to understanding concepts. Students with a 'memorize' stance focus on learning facts in isolation. Students with an 'understand' stance instead endeavor to understand and to be able to apply and link concepts and ideas.

A student's stance toward the autonomy necessary for learning science can range from holding others responsible for one's learning to taking personal responsibility for that learning. A student with an 'external responsibility' stance perceives teachers, peers, or family members as the key to whether or not they learn (or perform well in) science, whereas students who take personal responsibility put the emphasis on their own abilities or performance.

Motivational goals for students' participation in science class can range from performance goals to learning goals, as discussed by Ames (1992; Ames & Archer, 1988) and Dweck (1986; Dweck & Leggett, 1988). Students with a performance goal emphasize whether they get the right answer, and often are disinclined toward challenging work because they are less likely to "succeed" (perform well) when challenged. Learning-oriented students, on the other hand, focus on extending their own personal knowledge. According to the literature, these students typically thrive on challenges because they view them as likely to further their understanding.

Coding the Dimensions

While all dimensions of the taxonomy discussed above are considered both interesting and relevant, the current analysis is limited to those dimensions most appropriate given the particular nature of the CLP/KIE classroom: (a) autonomy for learning (personal or external responsibility); (b) strategy for learning (understand or memorize); and (c) process of scientific decision-making (dynamic or static). Table 7–1 summarizes these dimensions.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Continuum of Beliefs (low to high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy for Learning</td>
<td>External responsibility to Personal responsibility</td>
</tr>
<tr>
<td>Strategy for Learning</td>
<td>Memorize to Understand</td>
</tr>
<tr>
<td>Process of Science</td>
<td>Static to Dynamic</td>
</tr>
</tbody>
</table>

Table 7–1: Dimensions of Beliefs Investigated

In this research, I make a value judgment about the productivity of different beliefs. I view beliefs in personal responsibility for learning, understanding, and the dynamic nature of science to be more productive than beliefs in external responsibility, memorization, and a static nature of science. These views are more valued and more valuable in the particular class in which this research takes place; however, one can imagine that in other contexts other beliefs would be more productive. For example, in a traditional science class focused on memorization of terms, a belief in understanding might hinder students' success.

How did I code the dimensions? Each student received a score (between 0 and 10) for each dimension, based on their responses to the relevant multiple choice and check-off questions. These scores are similar to Schommer's (1994) "frequency distributions"; they are intended to indicate a student's position on a continuum. The items have been validated conceptually through discussions with experts and through comparison with free response and interview data. An example question addressing each dimension follows. (For a complete list of questions associated with each dimension score, see Appendix H.)
The first question (reproduced in part here) addresses the *autonomy* dimension:

When learning **new science material** I prefer to:

**(circle one for each statement)**

– be told what is correct by a teacher.  
  **always**  **sometimes**  **never**

– have a parent or teacher explain the right answer to me.  
  **always**  **sometimes**  **never**

For each “never” response, students receive a positive autonomy score, and for each "always" response, a negative score. Students' scores were totaled to find their overall *autonomy* score, which was then normalized to range from 0 (least autonomous) to 10 (most autonomous).

The following question addresses *strategy*:

"When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material."

**(circle one)**  
**Agree**  **Disagree**

If students agree, they receive a negative score, and if they disagree, a positive score. Again, totaled and normalized scores ranged from 0 (memorize) to 10 (understand).

The last example addresses *process*:

"The science principles in textbooks will always be true."

**(circle one)**  
**Agree**  **Disagree**

Here again, if they agree, they receive a negative score, and if they disagree, a positive score. And again, totaled and normalized scores ranged from 0 (static) to 10 (dynamic).

It is important to remember that students' responses should be considered both by individual dimension and as a whole. A particular response to an item may cause them to score negatively even though that action or belief is not inherently bad. For example, a student who said that they always like to be told what is correct by a teacher would receive a negative mark for *autonomy*. Of course, plenty of successful students ask the teacher for guidance. This is simply intended to serve as one of several indicators of the student’s autonomy. A student who never indicated (on any of the relevant items) a desire to check in with the teacher would obviously be considered more autonomous than one who consistently indicated the opposite. Students’ scores indicate their position on the continuum for the belief.

Having high scores in one dimension does not necessarily imply that the student will be successful. For example, continuing the example from above: If a student is consistently autonomous but adopts memorization as the best learning strategy, they are less likely to succeed than an autonomous understander, who would have scored high on both dimensions of the nature of learning. The dimensions need to be considered pieces of a puzzle, not completed puzzles unto themselves.

**Students' Performance and Learning**

Students' beliefs are linked in this chapter to their performance on the All The News project, as measured by the various measures discussed in the previous chapters, and their grade on the final exam for the course. The final exam covered all the concepts learned over
the course of the semester and was based mostly on students' ability to use the scientific principles they learned in class to explain everyday phenomena. The final exam grade primarily measures students' conceptual understanding. Note that in this chapter, unlike the two previous ones, students are considered at the level of the individual in addition to at the level of the pair.

Analyses

Students' responses to multiple choice and check-off items on the pre- and post-tests were coded and scored as discussed above. Statistical analyses using these scores include correlational analyses to compare scores in various dimensions for individual students. (Those correlations provide a foundation for the multiple regressions discussed in Chapter 8.) Three groups were assigned for each dimension, based on students' pre-test scores. Each "extreme" group for each dimension represents a tail of the distribution and includes approximately 20% of the students. (Because of the nature of the scoring system, the tails actually range from about 16% to 28% of the population.) ANOVAs using these groups further compare students. Gender analyses have also been performed for beliefs and performance on the quality measures.

Qualitative data include interviews with students as well as students' answers to the free response questions on the beliefs assessment. These qualitative data supplement the statistical analyses and enrich the data, and snippets from these data are interspersed throughout the results to demonstrate the relationships being discussed.

The interviews also allow a check on the scores assigned using the beliefs test. The interviews probed primarily the strategy and process dimensions. For the nine interviews (with three dimensions to assess for each), I made an assessment on 17 of the possible 27 dimension assessments. Only one of these was on the autonomy dimension. The beliefs portions of the interviews were limited to about 10 minutes, so I could not investigate fully all aspects of the students' beliefs. Of the 17 assessments made, all but one very closely matched the group assigned based on the pre-test score.

Results

We turn now to a discussion of the results of these analyses, first characterizing the range of students' beliefs, then demonstrating change over the course of the semester. Relationships among the dimensions and between the dimensions and other variables like performance and gender are then identified. To preview my findings, I show that the two dimensions of students' beliefs about learning science are not highly correlated with one another, but that both improve over the course of the CLP/KIE semester. Students' beliefs about autonomy are seen to be particularly important for their knowledge integration.

Characterizing "Productive" and "Less Productive" Beliefs

An investigation of students' beliefs about the autonomy, strategy, and process dimensions must start with a description of what productive and less productive beliefs in those dimensions would look like. Recall that productive beliefs here are those valued in the CLP/KIE classroom, in particular. Qualitative data—student interviews and responses to free response questions on the pre- and post-tests—are used to impart a better sense of the differences among students.
Autonomy for Learning Science

We turn first to the autonomy dimension. Students with the most productive beliefs about the autonomy of learning science believe that they have primary responsibility for what and how they learn. For example, one student who scored high in autonomy on the pre-test said, in an interview:

S412: Because...just because the teacher explains it right doesn’t mean that I can understand it correctly. When I know—when I do a problem right, then I know definitely I have it right.

On the other hand, students with less productive beliefs about autonomy place responsibility for their learning on their teachers or peers. For example,

I: So, why is it good to be told what is correct by a teacher, or have the teacher explain the right answer to you?

S514: ‘Cause if you don’t understand what you did wrong, you’d always think that that was the correct answer. And—you just wouldn’t know the right answer, and if somebody tells you what the right answer is, it’s better to know.

Students with less productive beliefs often answered a question about individual differences in the following way:

Do you think everyone learns science in the same ways as you do?

S307, Pre-test: Some teachers might teach their students in a different way.

S424, Pre-test: There are many different books and many different teachers and sources to learn science from therefore it has got to vary.

Such responses provide useful indicators of the less-productive belief of external responsibility for learning.

Strategy for Learning Science

Students who have very productive views of the strategy for learning science view understanding as a better strategy than memorizing. These students said things like,

S107: Well when you just memorize facts, you’re more likely to forget them than if you understood the meaning of the facts because if you understood the meaning of them, it would stand out more in your mind.

Students with less productive beliefs about strategy instead prefer memorizing facts. For example, one student, when asked about her preference for always ignoring ideas that do not make sense, responded:

I: Okay, so then this next one was “ignore the ideas that don’t make sense.” So tell me why—why is that good?

S514: To ignore the ideas that don’t make sense?

I: Yeah.
S514: If they don’t make sense, then why should we have to deal with it?

*Process of Science*

Students with a productive view of the *process* of science view it as a dynamic field in which decisions about scientific explanations are made based on evidence and theory. They typically view experimentation as the source for that evidence, but talk about experimentation differently than do students with less productive beliefs in this area. When asked about whether scientific principles in textbooks are always true, one student with high *process* beliefs said that textbooks need to be updated "with all the information that keeps coming in." This exchange followed:

I: So that new information that’s coming in. Where does it come from?

S107: Scientific discoveries of scientists from around the globe.

Another student spontaneously gave the example of cigarette smoking as a current controversy in science:

I: How would those two groups ever decide one way or the other?

S402: I guess they’d have to like—I don’t know, I guess they’d have to like, research more into that. I don’t really know how they’d figure that out [laughs].

I: Okay. So what do you mean by “research more,” “research into it?”

S402: Like, by doing experiments, like seeing, like if they had one chemical, like a certain group of chemicals or a chemical in a cigarette and having someone smoke that, and then that one not in the same cigarette and someone smoking that and just see how—the results, and things like that.

Other students with less productive beliefs about the process of science might see experimentation very differently. When asked how people would make a decision about what to include in science textbooks, one student said:

I: Okay. So how would they ever decide which one’s true?

S231: Both did the experiment side by side, watched each other and tried to look for the mistakes, if one person made a mistake or not.

Such students tend to see science as a collection of unchanging facts that are either right or wrong. Experimentation is viewed as a way to get at that truth.

We have seen a range of student beliefs in the three dimensions. How are these dimensions similar or different at the two times at which we have snapshots?

*Comparing Pre- and Post-test Results*

One research question is, how stable are students' beliefs? If beliefs are thought to be relatively stable, one would expect that students' views in each dimension would be highly correlated from the beginning to the end of the semester. It seems likely that a student with a very autonomous stance is likely to remain fairly autonomous, a student who strongly favors memorization will continue to favor memorization, and so forth. This expectation is
borne out by the analysis: Significant positive correlations existed between the pre- and post- scores for each dimension (p < .0001 in each case). See Table 7–2 for descriptive statistics and Table 7–3 for correlations. While this result is not surprising, it does support the assumption that students answer these multiple choice questions seriously and that their responses are thus meaningful.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy-Pre</td>
<td>4.124</td>
<td>1.528</td>
</tr>
<tr>
<td>Autonomy-Post</td>
<td>4.418</td>
<td>1.560</td>
</tr>
<tr>
<td>Strategy- Pre</td>
<td>6.474</td>
<td>1.577</td>
</tr>
<tr>
<td>Strategy-Post</td>
<td>6.829</td>
<td>1.642</td>
</tr>
<tr>
<td>Process-Pre</td>
<td>6.453</td>
<td>1.935</td>
</tr>
<tr>
<td>Process-Post</td>
<td>6.716</td>
<td>2.027</td>
</tr>
</tbody>
</table>

Table 7–2: Descriptive Statistics for the Dimensions (N = 174)

<table>
<thead>
<tr>
<th></th>
<th>Aut.-Pre</th>
<th>Aut.-Post</th>
<th>Strat.-Pre</th>
<th>Strat.-Post</th>
<th>Process.-Pre</th>
<th>Process.-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aut.-Pre</td>
<td>1.000</td>
<td>.412*</td>
<td>1.000</td>
<td>.517*</td>
<td>1.000</td>
<td>.370*</td>
</tr>
<tr>
<td>Aut.-Post</td>
<td>.412*</td>
<td>1.000</td>
<td>.517*</td>
<td>1.000</td>
<td>.370*</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 7–3: Correlations for Pre- and Post-Test Scores (N = 168; * = significant at p < .0001)

An example of the response of one student (who scored high on all three dimensions in both pre- and post-tests) to a question about learning is provided:

Do you think everyone learns science in the same ways as you do?

S402, Pre-test: No. I think that everyone has their own way of learning and understanding science. And that some ways that work for a certain person may not for others

S402, Post-test: No. I know that everyone understands science differently, because my friend understands things better when she does activities or experiments but I understand things in science better when I discuss about the concepts w/ someone else and when I'm able to see what's going on (like in pictures or written in a simple way or a prototype).

Since epistemological change is hard—but possible (see Carey et al., 1989)—to effect, one would not expect there to be a significant change over the 17 weeks of the semester. However, positive change did occur: Paired t-tests indicated that the students in this study improved significantly in their views of both strategy (t[167] = 3.227, p = .0015; effect size = 23%) and autonomy (t[167] = 2.168, p = .0316; effect size = 19%). In other words, overall, students became more likely to view understanding as a good strategy for learning and became more likely to view themselves as responsible agents for their learning. (There was only a slight improvement in students' process scores; effect size = 14%). Figure 7–1 presents the mean scores for each dimension.
The following is an excerpt from one student whose beliefs about both *strategy* and *autonomy* improved over the course of the semester. This student explicitly discussed experiences from the class on the post-test:

“I expect most of the ideas in science class to connect to a few big ideas.” (agree or disagree)

S529, Post-test: Agree. I think that the ideas we learned in class do connect with one big idea. For example, when we learned about light we learned about how it changes into different energies, how it is reflected, how it is absorbed, how far it travels, what the intensities are, etc. I don't expect all of the things we learn to be connected, but I think that in all of my classes the little things we learn help us understand the main idea the teacher wants us to learn.

Further analysis investigates which groups of students are changing the most, and in what direction. Are "good" students getting better? Or are the improvements over the course of the semester achieved mainly by the students who start out with less productive beliefs? ANOVA analyses of the three groups within each dimension indicate that the latter is the case. For each dimension, there was a significant difference between the groups' mean change in score for that dimension. In other words, for *autonomy*, the low group's mean change on autonomy (pre- to post-) was significantly different from the middle and high groups' mean change on autonomy ($F[2, 165] = 27.852, p < .0001$). The same was true for the other two dimensions, as well ($strategy: F[2, 165] = 11.843, p < .0001; process: F[2, 165] = 30.925, p < .0001$). In each case, the low group's mean increased a fair amount, the middle group's mean increased a small amount, and the high group's mean went down. See Figures 7–2, 7–3, and 7–4.
Figure 7–2: Mean change in autonomy scores for each autonomy group (group 1 = least autonomous, group 3 = most autonomous)

Figure 7–3: Mean change in strategy scores for each strategy group (group 1 = memorizers, group 3 = understanders)
Figure 7–4: Mean change in *process* scores for each *process* group
(group 1 = static, group 3 = dynamic)

12 cases were omitted due to missing values.
The frequency distributions for the dimensions indicated that there are no instances of floor effects. The only possible instance of a ceiling effect was in the process dimension. Seven students scored a 10 on process for the pre-test, and by the post-test, this number went up to 13 students. With the possible exception of a ceiling effect on the process dimension, a regression to the mean may be a better explanation for the improvement of the lower groups and the decline of the higher groups.

What do students whose beliefs change over the course of the semester say? Here is an example of a student who scored low on all of the dimensions on the pre-test.

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S204, Pre-test: Because when you memorize the facts then you know them for the test and you will get an A. It is not too hard.

“I expect most of the ideas in science class to connect to a few big ideas.” (agree or disagree)

S204, Pre-test: I don't do big things.

By the post-test, this student's beliefs had changed considerably:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S204, Post-test: I think that it is better to understand and know the fact than just memorizing it because then you can see how it works and you can picture it in your everyday life, but if you just memorize the fact you may get a good grade on the test but the labs will be harder.

“I expect most of the ideas in science class to connect to a few big ideas.” (agree or disagree)

S204, Post-test: I think that most of the ideas will connect to some big ideas later on like maybe in high school or something. Ideas like black absorbs heat white reflects heat. We did a lot of little experiments where we would find out little ideas that later connected to the idea that white reflects heat energy and black absorbs the heat energy, and maybe later on in school this idea will connect to an even bigger idea.

Clearly this student's attitude toward science class improved considerably; it appears that the student's beliefs about science and learning science improved, as well. (This student did quite well on the final exam, too, although the response to the second post-test question indicates some conceptual confusion about light and heat.)

Relating Epistemological Dimensions

One might intuit that students who have productive beliefs in one dimension would have productive beliefs in all dimensions. The current analysis allows us to probe these relationships between students' views of the nature of science and of the nature of learning, by looking at relationships between individual dimensions before and after students experienced the curriculum.
The Nature of Learning

Broad-brush representations of students' views of the nature of learning typically assume that "good" students understand what learning is all about, and are "good" at the various aspects of learning. This assumption is not supported by the current analysis. The two dimensions of students' views of the nature of learning, autonomy and strategy, were only slightly positively correlated ($r_{174} = .128$, $p = .0926$) at the time of the pre-test and were not correlated at all by the end of the semester. See Table 7–2 for descriptive statistics and Table 7–4 for correlations.

<table>
<thead>
<tr>
<th></th>
<th>Autonomy-Pre</th>
<th>Strategy-Pre</th>
<th>Process-Pre</th>
<th>Autonomy-Post</th>
<th>Strategy-Post</th>
<th>Process-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy-Pre</td>
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<td>.128</td>
<td>.039</td>
<td>1.000</td>
<td>-.039</td>
<td>.035</td>
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<tr>
<td>Strategy-Pre</td>
<td>.128</td>
<td>1.000</td>
<td>.389*</td>
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<tr>
<td>Process-Pre</td>
<td>.039</td>
<td>.389*</td>
<td>1.000</td>
<td>.035</td>
<td>.354*</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 7–4: Correlations between Dimensions (N = 174; * = significant at $p < .0001$)

Students can have very productive views of the strategy of learning—that is, they perceive understanding as the best way to learn science—but can simultaneously hold less productive beliefs about autonomy—that is, they put the responsibility for learning on the teacher or someone else. Here are two statements from a student whose post-test scores indicate that she was an "understaner":

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S505, Pre-test: Disagree. The whole point of learning things in class is to understand the complicated material you should not try to just memorize that cause what if the teacher asked you to explain the material what are going to say ' I just focused on memorizing the material sorry I can't' No you wouldn't because you would get a bad grade.

Do you think everyone learns science in the same ways as you do?

S505, Pre-test: No. Different teachers.

This student, in response to the second question, indicates that the teacher bears responsibility for students' learning.

Conversely, students can be autonomous memorizers:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S112, Pre-test: Agree. Memorizing is always a good idea because you will keep it in your mind for a while and you don't have to review what you memorized.

Do you think everyone learns science in the same ways as you do?
S112, Pre-test: No. Everybody has their own way of studying and memorizing.

Interestingly, this student appears to equate learning with memorizing.

*The Nature of Learning and the Nature of Science*

To what extent are the two dimensions of the nature of learning linked to the *process* dimension of the nature of science? Of the two linkages, a *strategy-process* correlation seems more likely—and in fact these two dimensions were highly correlated (r[174] = .389 for pre-test; r[174] = .354 for post-test; p < .0001 in each case) at both the pre-test and post-test windows (unlike autonomy and process, which were not correlated). (Again, see Table 7–2 for descriptive statistics and Table 7–4 for correlations.) This finding was corroborated by ANOVAs testing the scores of different groups: I found a significant difference in the low, middle, and high *process* groups' mean *strategy* scores (F[2, 171] = 15.938, p < .0001) and the *strategy* groups' mean *process* scores (F[2, 171] = 16.902, p < .0001).

This means that students who see science as a dynamic process with decisions made on the basis of evidence are more likely to view understanding as the best strategy for learning science. For example, the following snippets are from a student who scored high in both *process* and *strategy* on the pre-test:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S402, Pre-test: Disagree. I've tried to memorize only the facts for a test and didn't get such a good grade since I didn't take time before to learn the 'hard' stuff (the main material on the test).

“The science principles in textbooks will always be true.” (agree or disagree)

S402, Pre-test: Disagree. Textbooks from a while back probably had principles that have today been proven wrong so I believe maybe in the future ideas that we have today (in textbooks) will be studied further and more will be added to the principles or they'll be changed.

Here is another student who scored high in *process* and *strategy* on the pre-test:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S507, Pre-test: Disagree. Memorizing facts is good but you really have to try to understand the complicated material. This is why when I am confused about a new idea I ask someone who understands the idea like my teacher to explain it to me.

“The science principles in textbooks will always be true.” (agree or disagree)

S507, Pre-test: Disagree. A lot of the principles in textbooks are just theory while some may be true. Like if you said hydrogen was a gas that would be true but if you said that the Big Bang formed the universe that would be just theory.

On the other hand, students who see science as a collection of static facts are more likely to view memorization as the best strategy for learning science:
“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S526, Pre-test: Agree. I would like to memorize facts better than trying to understand complicated material because it is easier for me to do.

“The science principles in textbooks will always be true.” (agree or disagree)

S526, Pre-test: Agree. I mostly agree because in textbooks they give you facts about animals computers etc.

Another student with low scores on the strategy and process dimensions had this to say:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S423, Pre-test: Agree. Learning some facts would be easier than listening to the teacher tell you alot of stuff at once.

“The science principles in textbooks will always be true.” (agree or disagree)

S423, Pre-test: Agree. I think they will because they wouldn't be in the book if they weren't correct

These results indicate that students are behaving reasonably in their approach to learning science: If one sees science as a collection of facts, memorization would be a good strategy for learning it! Unfortunately for these students, this approach is likely to fail in a curriculum like CLP/KIE, where conceptual understanding of ideas plays a much larger role.

Relating Beliefs to Performance

We have seen that the broad-brush representation of students, which would likely indicate beliefs about learning are highly correlated, is inadequate. We might also naively assume that students with "good" beliefs end up with "good" grades. To what extent is this true? Do specific dimensions of beliefs co-vary with performance? The standard project quality measures—project score, critique quality, coherence of ideas, and guidelines quality—are used here, as well as grade on the final exam.

Students' pre-test scores for strategy and process were both significantly correlated (p = .0001 for each dimension) with overall project score, though the correlations are low. Post-test scores for all three dimensions were significantly correlated with the All The News score (M = 81.8, SD = 9.5, N = 178). See Table 7–2 for descriptive statistics and Table 7–5 for correlations.
Table 7–5: Correlations for Dimensions and Performance (* = significant at p < .05; pre-: N = 172; post-: N = 174 for project score, N = 170 for final exam grade)

<table>
<thead>
<tr>
<th></th>
<th>Autonomy-Pre</th>
<th>Autonomy-Post</th>
<th>Strategy-Pre</th>
<th>Strategy-Post</th>
<th>Process-Pre</th>
<th>Process-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Project Score</td>
<td>.129</td>
<td>.167*</td>
<td>.289*</td>
<td>.332*</td>
<td>.290*</td>
<td>.201*</td>
</tr>
<tr>
<td></td>
<td>p = .0272</td>
<td>p = .0001</td>
<td>p &lt; .0001</td>
<td>p &lt; .0001</td>
<td>p = .0001</td>
<td>p = .0077</td>
</tr>
<tr>
<td>Final Exam Grade</td>
<td>.043</td>
<td>.131</td>
<td>.163*</td>
<td>.314*</td>
<td>.084</td>
<td>.129</td>
</tr>
<tr>
<td></td>
<td>p = .0332</td>
<td>p = .0332</td>
<td>p &lt; .0001</td>
<td>p &lt; .0001</td>
<td>p &lt; .0001</td>
<td>p &lt; .0001</td>
</tr>
</tbody>
</table>

We can also investigate the relationship between pairs’ autonomy, strategy, and process beliefs with their performance on the specific project quality measures. Correlational analyses indicate that pairs’ pre-test beliefs about autonomy played an important role for students who received generic prompts and that pairs’ pre-test beliefs about the process of science played an important role for those who received directed prompts. Pairs’ pre-test beliefs about strategy were especially important for students who received generic prompts in terms of their overall project scores, but were only slightly related to any of the specific measures. Table 7–6 presents these results.

In particular, we see that highly autonomous students in either condition were likely to develop very coherent ideas. These students may be accustomed to the act of identifying weaknesses in their understanding for themselves, and may take action to integrate their knowledge. However, only for students in the generic prompt condition was autonomy related to overall critique quality. Students who take responsibility for their own learning may be more likely to identify weaknesses in their current understanding and may be better able to identify weaknesses in evidence and claims, as well—especially when the students are given free rein over the direction of their reflection.
Table 7–6: Correlations for Pairs' Beliefs and Project Quality Measures

(* = significant at p < .05)

The relationship between individual students' beliefs and their final exam grade is more straightforward (see Table 7–5 for correlations). The post-test scores for strategy were significantly positively correlated with final exam grade (M = 73.0, SD = 18.0; post-: r[170] = .314, p < .0001, as shown in Table 7–5). This indicates that students who perform well on the final exam (which emphasizes understanding and requires few, if any, memorized facts) are likely to believe that learning science is best accomplished by trying to understand it. One student who scored well on the final exam summarized her belief about the importance of understanding:

“When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material.” (agree or disagree)

S522, Post-test: Disagree. If you just memorize the facts then you won't really understand it, and if you get into a situation that is similar, but not the same as what you memorized, you won't know what to do because you won't know what information to alter to make it fit your situation.

One note about student performance: Students' overall project scores and final exam grades were significantly correlated (r[174] = 0.289, p < .0001). This provides corroboration for the intuition that good students tend to be consistent in their high performance.
**Relating Beliefs and Reflection**

Correlational analyses crossing pairs' beliefs and the most interesting kinds of reflection (as pointed to by the analyses in Chapter 6) indicate no significant relationships between students' beliefs and the focus of their reflection.

**Comparing Males' and Females' Beliefs**

Females continue to be underrepresented in science, and that underrepresentation is known to start early. Do eighth-grade boys and girls differ in their perceptions of science and science learning? By the end of the semester, any marginal differences in girls' and boys' beliefs disappeared; the CLP/KIE curriculum may act as an equalizer. See Appendix O for the details of these analyses. (There were also no significant differences in boys', girls', or mixed pairs' project quality scores.)

**Discussion**

How can we integrate these findings? How can we answer questions about the development of beliefs and their ramifications? We turn first to a discussion of the link between the *strategy* and *process* dimensions.

*Why are strategy and process related?*

There exist at least three possible explanations for the strong correlations between students' views of the process of scientific decision-making and of the appropriate strategy for learning science. The first hypothesis is that *strategy* and *process* are independent measures that happen to co-vary. A second hypothesis is that *strategy* and *process* are causally linked, and when students develop a view that science is a dynamic process, they are likely to develop a stance toward learning science that involves understanding as opposed to memorizing. A third hypothesis is that *strategy* and *process* are causally linked, but when students develop a stance toward learning science that involves understanding as opposed to memorizing, they are likely to develop a view that science is a dynamic process.

Which hypothesis seems most likely? For which do we have most evidence? As a science educator, my intuition (and hope) was that students' views of *strategy* and *process* are causally linked—that developing a dynamic view of science leads people to realize that they should attempt to understand the concepts in science rather than simply memorizing facts. If that were the case, we could work on teaching students about the nature of science, and expect good learning strategies to fall out naturally from that instruction.

The data do not conclusively support or contradict the second or third hypotheses, however. In none of the interviews do students make an explicit link between their belief about the process of science and their preferred strategy for learning science. The free response questions on the test do not provide explicit linkages, either. The strongest statement we can make about these two dimensions is that of a simple correlation: Students who view science as a dynamic field are likely to try to understand science concepts, and students who view science as static tend to try to memorize science facts.

A single force may drive both results, though. It is possible that some students have added sense-making to their repertoire of ideas. These students may then apply that idea to both themselves (science learners) and scientists (science practitioners), and see the importance
of linking ideas and discriminating among them for both themselves and scientists. Others may hold a "fact" or "truth" orientation to the world (see Driver et al., 1996), and may apply that orientation to themselves and to scientists. Further research is necessary to determine if this new hypothesis is tenable.

**Why is there not a strong relationship between strategy and autonomy?**

Many educators may be surprised by the finding that some students have disparate beliefs within the realm of the nature of learning; our intuitions often tell us otherwise. But different experiences may come into play in the development of these beliefs, and there are also different rewards for each.

Students may come to be autonomous for a variety of reasons, from having a shy personality to being discouraged from asking questions at home to having a feeling of confidence in oneself and one's ability. However, autonomy, while virtually a requirement for success in college and the working world, may not be imperative for success at the middle school level, even in a class like CLP/KIE. In a more traditional middle school science class, autonomy may find even less reward.

Students' strategies for learning science are also likely to develop from a myriad of foundations. Most students have experienced science class as a venue for knowing facts and memorizing definitions, and so is not surprising that many students see memorization as the most appropriate strategy for learning science. However, some students recount formative experiences when they realized that memorizing was insufficient and/or less efficient than understanding, and these students typically have moved instead toward attempting to achieve a conceptual understanding of science ideas. A strategy of understanding is rewarded in a class like CLP/KIE, where students are applying scientific principles to everyday phenomena.

It appears quite reasonable that students' views of autonomy and strategy develop and act independently, given the different experiences that may lead to them and the rewards or disincentives students may experience as a result of their behaviors.

**Summary and Implications**

What conclusions can we now draw about improving science instruction? The scaffolded knowledge integration framework can help us make recommendations for ways to encourage the development of more productive beliefs about science.

Teaching that emphasizes understanding, application, and explanation may particularly help students make gains in their views of appropriate learning strategies—that is, it appears to help students see the importance of conceptual understanding. Secondly, high strategy beliefs were correlated with high final exam grades, indicating that adopting a strategy of understanding is likely in fact to lead to a higher actual conceptual understanding. Thus, teaching and curriculum that encourage a stance toward understanding may be particularly helpful to students. Work by Smith and her colleagues in Hennessey's classroom indicates that extended exposure to teaching of this ilk can have strong effects on students' beliefs (Smith, Houghton, & Maclin, 1997). Furthermore, the beliefs of students who started out with less productive beliefs improved more than those of students who started out with more productive beliefs. Innovative teaching and technology may particularly help the students who need it the most. In the CLP/KIE classroom, understanding is encouraged in
part through the kind of sense-making and knowledge integration modeled by the teacher. He attempts to make his own thinking (about the importance of conceptual understanding and autonomy) visible through his teaching.

The qualitative data do not support or contradict a causal link between students' views of the process of science and their strategy for learning science. However, since these dimensions co-vary, instruction should emphasize the dynamic nature of science and the importance of conceptual understanding. Once students identify the strategy of "understanding" or "sense-making" and add it to their repertoire of ideas, they may apply it to themselves and scientists, simultaneously improving their understanding of science as a field and increasing their propensity toward knowledge integration. Supporting students in recognizing "sense-making" as a relevant and accessible model for learning is likely to be of benefit.

Third, large projects focusing on knowledge integration, like KIE projects, are likely to encourage and reward a strategy of understanding. Since KIE projects require a broad range of skills and expertise, more students are able to succeed, because their own expertise is likely to be of benefit. Collaboration also plays an important role. Students benefit from social supports for learning. Collaboration allows students to have exposure to more productive beliefs, which they may add to their repertoire. (Of course, students will also be exposed to less productive beliefs.)

Finally, although autonomy is not necessarily rewarded by all aspects of middle school curricula, it is a skill lifelong learners need. We saw a high positive correlation between autonomy and each of the project quality measures—especially coherence. Therefore, instruction should encourage autonomy. In the CLP/KIE classroom, technology scaffolds students to allow them to be autonomous without flailing. Perhaps more importantly, innovations such as reflection prompts encourage regular reflection and thus facilitate students' autonomous knowledge integration, as discussed in depth throughout this dissertation.

In previous chapters I reviewed the gross effects of directed and generic prompts, and have investigated the role of reflection in student learning. In this chapter, we have characterized students' beliefs about science and learning science. How does this all fit together? The next chapter will synthesize all the results to help us in drawing conclusions about instructional interventions to encourage productive reflection for all students.