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ABSTRACT

This paper investigates middle school students' particular beliefs about the process of scientific inquiry as well as their beliefs about learning science, specifically the level of autonomy appropriate and their preference for memorization or understanding. Data collection instruments included a beliefs assessment, measures of student performance, and interviews. Results indicate that students with a dynamic view of the process of science are likely to try to understand science, whereas those who view science as a static field expect to memorize facts. Students that believed understanding is the best strategy for learning science scored highest on the final exam. Other findings indicate that although students improve overall in the productivity of their beliefs over the course of the semester, students who start out with less productive beliefs improve more than do students who begin with productive beliefs. Finally, although girls and boys differ in their beliefs at the beginning of the semester, this difference disappears after participation in a semester-long innovative physical science curriculum. Instructional implications of these findings are discussed. An appendix contains a copy of the Relevant Questions on Beliefs Test. Contains 25 references. (JRH)

Students' Epistemological Beliefs about Science and Learning

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Abstract

My research investigates ways of analyzing students' beliefs about science and science learning. Based on Songer and Linn's (1991) taxonomy of static, dynamic, and mixed beliefs and on their assessment instrument for identifying students' beliefs, I have developed a method of analysis to investigate the different dimensions attained in the assessment tool. This research investigates middle school students' particular beliefs about the process of scientific inquiry as well as their beliefs about learning science—specifically, the level of autonomy appropriate and their preference for memorization or understanding.

The results indicate that students with a dynamic view of the process of science are likely to try to understand science, whereas those who view science as a static field instead expect to memorize facts. Students who believe understanding is the best strategy for learning science scored highest on the final exam. Interestingly, autonomous students are not necessarily those with the most productive learning strategies. Other findings indicate that although students improve overall in the productivity of their beliefs over the course of the semester, students who start out with less productive beliefs improve more than do students who begin with productive beliefs. Finally, although girls and boys differ in their beliefs at the beginning of the semester, this difference disappears after participation in a semester-long innovative physical science curriculum. Instructional implications of these findings are discussed.

Introduction

Over the past several years, educational research has emphasized the importance of conceptual understanding, of critical thinking, of lifelong learning. Why, then, investigate students' epistemological beliefs? What roles could beliefs play in the learning of concrete ideas and concepts? The current investigation addresses these questions, particularly with regard to students' learning of science.

The goals of this paper are to (a) identify and describe different dimensions of students' beliefs about both the nature of science and the nature of science learning, (b) determine how those dimensions relate to one another and to student performance, (c) investigate how beliefs change over time, and (d) compare the beliefs of girls and boys. Through these analyses, I link beliefs to learning and identify ways in which knowledge of students' beliefs might help us develop pedagogy and curricula better suited for the students in our science classrooms.

Integrated understanding is the "ability to link ideas to solve a complex and relevant scientific problem" (page 34-36, Linn, 1992b). What influences students' propensity toward knowledge integration? One influence may be their epistemological beliefs about science as a field and about themselves and their own learning. 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. 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 have some effect on their long-term progress in addition to their short-term performance in science class (Eylon & Linn, 1994). 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.

We turn now to a more complete discussion of the research setting and the work's theoretical underpinnings, followed by a discussion of the specific dimensions of students' epistemological beliefs under investigation here

The Research Setting

This research takes place in an eighth-grade physical science classroom using innovative curricula and technology to enhance students' science learning and their understanding of science. Using the Knowledge Integration Environment, students complete projects drawing on scientific evidence from the World Wide Web (Bell, Davis, & Linn, 1995). KIE blends custom and commercially-available software. The KIE software is used by students participating in curriculum units developed by the KIE research group and others. Those units, called "projects," are designed to encourage a deep understanding of science concepts rather than a collection of scientific facts, and have been used successfully as a venue in which students can apply the science principles they have been learning in class. KIE projects fall in three major categories: critiques, theory comparisons, and design projects. Critique projects foster the development of a critical eye when using evidence and evaluating arguments. Theory comparisons help students see that multiple sides may exist to arguments and that evidence should be used effectively to improve those arguments. Design projects engage students in an application of their knowledge.

Among other sites, KIE is being implemented in the Computer as Learning Partner (CLP) classroom (Linn, 1992a). CLP provides a one-semester curriculum introducing the physical science topics of thermodynamics and light to eighth-graders. In the curriculum, which is laboratory-based, the computer is used as a tool to collect and graph real-time data, perform simulations of experiments, and help students track their progress. The KIE software and curricula have developed directly out of CLP's decade of research on designing curricula and technology for middle school science teaching and learning.

KIE and CLP are guided by the idea of "scaffolded knowledge integration," an instructional framework supporting conceptual change. Conceptual change can be characterized as involving the differentiation and integration of ideas; thus to undergo conceptual change students need to expand their repertoire of ideas, discriminate between those ideas, and reorganize them through making conceptual links (Linn & Eylon, 1996). The scaffolded knowledge integration framework involves four elements (Linn, 1995). First, instruction should make thinking visible to students by illustrating diverse forms of expertise and reasoning about scientific phenomena. Second, instruction should identify accessible models for scientific phenomena to help students connect new information to existing knowledge and to problems that are both familiar and relevant. Third, instruction should provide social supports for the students so all students are encouraged in their science learning. Finally, students should be engaged as lifelong, autonomous learners so they can recognize the various sides of arguments, identify weaknesses in their own and others' arguments, and identify ways to strengthen those arguments.

Theoretical Underpinnings

Students' epistemological beliefs about their own learning and about the nature of science are sometimes viewed as influencing how they learn science. Most research, however, has focused on either one or the other of these aspects of students' epistemologies, while the intersection—students' beliefs about themselves as science learners—provides an interesting and largely untapped area of research.

Briefly, research has identified student beliefs and traits in the areas of the nature of learning, motivation, and science. Possible beliefs about learning include beliefs in quick learning, certain knowledge, simple knowledge, and innate ability (Schommer, 1990, 1993). Possible beliefs about motivation include performance versus learning or mastery goals (Ames, 1992; Ames & Archer, 1988; Dweck, 1986; Dweck & Leggett, 1988). Possible beliefs about science include a static, relativistic, or dynamic stance toward the areas of scientific explanations, parsimony, relevance, and learning (Linn & Songer, 1993; Songer & Linn, 1991). Within physics specifically, students may vary in their beliefs about the structure and content of physics and about learning physics (Hammer, 1994). Students also vary in their understanding of the purposes of predicting, experimenting, and questioning in science (Carey, Evans, Honda, Jay, & Unger, 1989; see also Carey & Smith, 1995). And, each of these beliefs about learning or science may be further influenced by the disposition the student has regarding that belief; that is, the inclination they have toward it, their sensitivity toward situations in which it is relevant, and their ability to modify their behavior based on the belief (Perkins, Jay, & Tishman, 1993).

Students' success in science class is related to their epistemological beliefs (see, for example, Eylon & Linn, 1994; Linn & Songer, 1993; Songer & Linn, 1991). Linn & Songer's (1993) characterization of students' beliefs identifies students as having static or dynamic views of science. About 20% of the students are in each of these extreme groups; the remaining 60% of the students have relativistic or mixed views of science (Linn & Songer, 1993). A student's stance toward science was assessed based on answers to questions relevant to four distinct topics: scientific explanations, parsimony, relevance, and learning.

According to Linn and Songer (1993), a student with dynamic beliefs views science as understandable, interpretive, and integrated with the world around them. These students 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 new material. Students with static beliefs, on the other hand, view science knowledge as static, memorization-intensive, and separate from their everyday lives. They see scientists as simply adding to the total store of knowledge rather than debating alternative perspectives.

Investigating the Nature of Science and the Nature of Learning

My research investigates ways of further analyzing students' beliefs about science and science learning. Based on Songer and Linn's (1991) taxonomy of static, dynamic, and mixed beliefs and building from their instrument for identifying students' beliefs, I have developed a method of analysis to investigate the different dimensions delineated by the assessment tool. A natural question after reviewing the related literature is: To what extent are students' views about *science* and about *learning science* linked to one another? Songer and Linn characterized students as static or dynamic using measures of both aspects of their epistemologies. Separate measures for these two areas allows assessment of relationships or distinctions between these dimensions.

What are the dimensions that make up a student's view of the nature of science? What are the dimensions of a view of the nature of learning? Table 1 shows a summary of a non-comprehensive list of interesting dimensions, based on exploratory interviews and a review of the existing literature.

Epistemology of...	**Dimension**	**Characteristics**
Nature of Science	*Use of Science*	Relevant or Irrelevant
	Process of Science	Dynamic, Mixed, or Static
Nature of Learning	*Strategy for Learning*	Understand Ideas, Comprehend Pieces, Memorize Facts
	Autonomy of Learning	Internal or External Responsibility for Learning
	Goal of Schoolwork	Learning Goal or Performance Goal

Table 1: Dimensions of Student Beliefs

This taxonomy builds on work done by others, as reviewed in part in the previous section. A partial list of acknowledgments can be made. For example, the Use and Process of science dimensions are investigated by Linn and Songer (1993), as "relevance" and "explanations." Other dimensions similar to Process include Carey's "guiding ideas and questions" (Carey et al., 1989); Ryan and Aikenhead's (1992) "knowledge in science" and "scientific method", Burbules and Linn's (1991) "scientific evidence," Hammer's (1994) "content of physics," and even Schommer's (1990, 1993) "certainty of knowledge." The Strategy dimension within the nature of learning area clearly builds on the work of Schommer, Hammer, and Linn and Songer. The Autonomy dimension builds on Hammer's "learning of physics" and

Schommer's "source of knowledge." And, as a last example, the Goal dimension builds on work done by Ames and Archer (1988; Ames, 1992), Dweck and Leggett (1988), Schommer, and Schoenfeld (1987).

We turn now to a more detailed review of the taxonomy, concentrating first on students' views of the nature of science, 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 Process fall along a continuum of (borrowing terminology from Songer and Linn) '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—particularly, 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. These students typically thrive on challenges because they view them as likely to further their understanding.

Assessing Beliefs

These dimensions were originally investigated through an in-depth case study analysis of three students using a written instrument similar to the one used in the current study 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. It was 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 how can we assess the beliefs of *all* students in a class? The current research uses an assessment instrument pioneered by Songer and Linn (1991; Linn & Songer, 1993) in the CLP classroom. 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 survey used in the current research, for example, does not contain any items on parsimony (Linn and Songer's most troublesome category) but has added new items on students' motivational goals.

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 current survey includes 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 technology and in particular 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 would 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 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.

We turn now to a more complete discussion of the methods employed in the current study.

Methods

The beliefs assessment used in the current analysis was given to a group of approximately 180 eighth grade students taking a one-semester course using the CLP and KIE software and curricula. An identical assessment was given at the beginning and end of the course. (These assessments are referred to as the "pre-test" and "post-test" throughout the rest of the paper.) 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.

Two straightforward measures of student performance are used in this analysis. The first, the grade on a large KIE project focusing both on critiquing and on elementary thermodynamics concepts, represents an amalgamation of facets of student performance, including conceptual understanding, critical thinking, ability to work with a partner, coherent writing ability, and ability to manage time to complete a large (8-day) science project. The second measure is the grade on the final exam for the course, which covered all the concepts learned over the course of the semester and is based mostly on students' ability to use the scientific principles they have learned in class to explain everyday phenomena. The final exam grade primarily measures students' conceptual understanding.

Furthermore, 24 students were interviewed about their epistemological beliefs as well as their conceptual understanding of a complex science problem. Nine of these interviews provide qualitative data for the current study, with the nine students representing a wide range of initial beliefs.

Dimensions of beliefs investigated

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) Process of scientific decision-making (dynamic or static); (b) Strategy for learning (understand or memorize); and (c) Autonomy for learning (personal or external responsibility).

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 the Appendix.)

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, scores were totaled and normalized to range 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, scores were totaled and normalized to range 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 considers memorization as the best learning strategy, they are less likely to succeed than an autonomous understander. The dimensions need to be considered pieces of a puzzle, not completed puzzles unto themselves.

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. 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.

Qualitative data include student interviews 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. (Students' responses to test questions have been cleaned up to eliminate any particularly confusing typographical errors; some of the less distracting errors have been retained.)

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), an assessment could be made on 17 of the possible 27 dimension assessments (only one of these was on the Autonomy dimension). Of the 17 assessments made, all but one matched the group assigned based on the pre-test score or were off by a single step (between high and medium or medium and low).

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 (a) among the dimensions and (b) between the dimensions and other variables like grades and gender are then identified.

How can we characterize "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. We use the qualitative data—student interviews and responses to free response questions on the pre- and post-tests—to get a better sense of the differences among students.

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 answer 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.

Students who have very productive views of the strategy for learning science view understanding as a better strategy than memorizing. These students say 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, responds:

> 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 about it?

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 gives 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 says:

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 which 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?

How do pre- and post-test results compare?

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: t-tests indicate significant positive correlations between the pre- and post-scores for each dimension ($p < .0001$ in each case). See Table 2 for descriptive statistics and Table 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.

	Mean	Standard Deviation
Autonomy-Pre	4.124	1.528
Autonomy-Post	4.418	1.560
Strategy- Pre	6.474	1.577
Strategy-Post	6.829	1.642
Process-Pre	6.453	1.935
Process-Post	6.716	2.027

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

	Autonomy-Pre	Autonomy-Post		Strategy-Pre	Strategy-Post		Process-Pre	Process-Post
Autonomy-Pre	1.000	0.412*	Strategy-Pre	1.000	0.517*	Process-Pre	1.000	0.370*
Autonomy-Post	0.412*	1.000	Strategy-Post	0.517*	1.000	Process-Post	0.370*	1.000

Table 3: Correlations for Pre- and Post-Test Scores (* = significant at $p < .05$)

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 indicate that the students in this study improved significantly in their views of both Strategy ($t[167] = 3.227$, $p < .05$) and Autonomy ($t[167] = 2.168$, $p < .05$). 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.) Figure 1 presents the mean scores for each dimension.

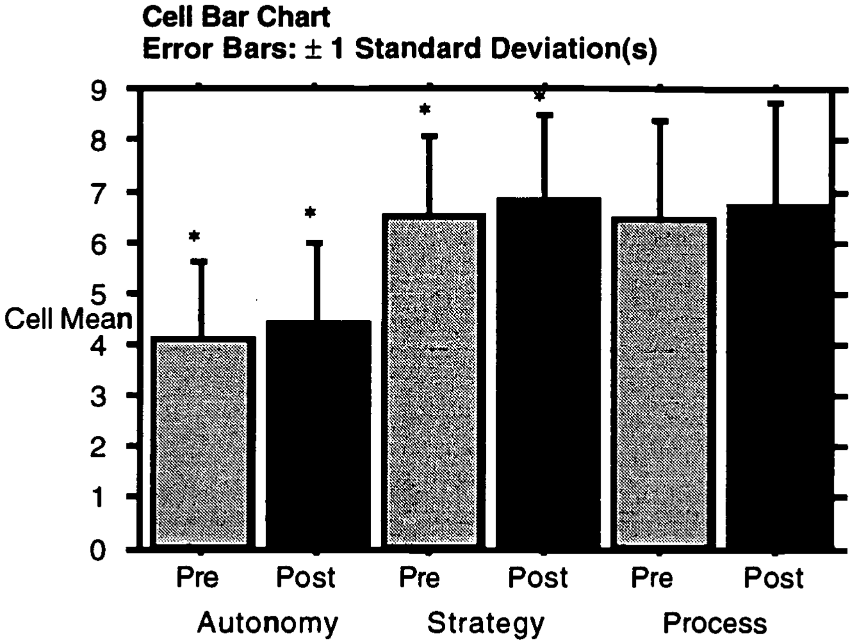
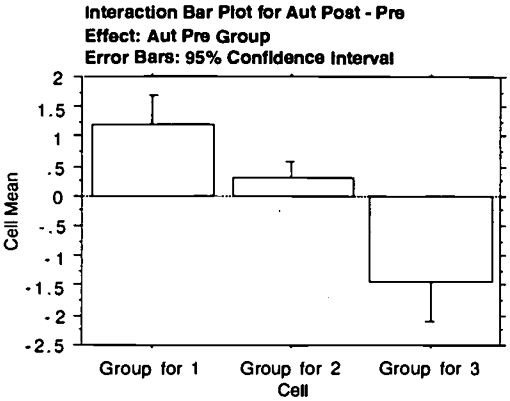


Figure 1: Mean Dimensions Scores on Pre- and Post-Tests (* = significant at p < .05)

The following is an excerpt from one student whose beliefs about both Strategy and Autonomy increased over the course of the semester. This student explicitly discusses experiences from the class on his post-test:

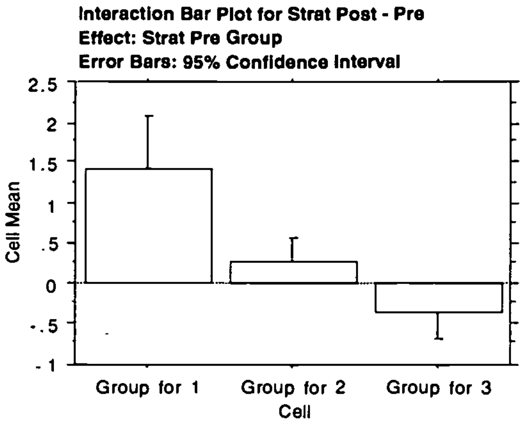
> "I expect most of the ideas in science class to connect to a few big ideas." (agree or disagree)
>
> S529, Post-test: Agree. I think that the ideas we learned in class do connect with one big idea. For example, when we learned about light we learned about how it changes into different energies, how 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 is 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-) is significantly different from the MIDDLE and HIGH groups' mean change on Autonomy (F[2, 165] = 27.852, p < .0001). The same is 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 2, 3, and 4.



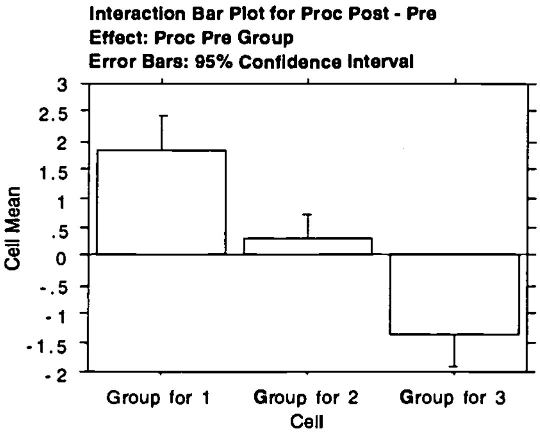
12 cases were omitted due to missing values.

Figure 2: Mean change in Autonomy scores for each Autonomy group (group 1 = least autonomous, group 3 = most autonomous)



12 cases were omitted due to missing values.

Figure 3: Mean change in Strategy scores for each Strategy group (group 1 = memorizers, group 3 = understanders)



12 cases were omitted due to missing values.

Figure 4: Mean change in Process scores for each Process group (group 1 = static, group 3 = dynamic)

The frequency distributions for the dimensions indicate that there are no instances of floor effects. The only possible instance of a ceiling effect is 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, Pre-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 has improved considerably; it appears that the student's beliefs have 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.)

How are the epistemological dimensions related?

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.

Relationships among Dimensions of 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 held out by the current analysis. The two dimensions of students' views of the nature of learning, Autonomy and Strategy, are only slightly positively correlated ($p = .09 < .1$) at the time of the pre-test and are not correlated at all by the end of the semester. See Table 2 for descriptive statistics and Table 4 for correlations.

	Autonomy-Pre	Strategy-Pre	Process-Pre		Autonomy-Post	Strategy-Post	Process-Post
Autonomy-Pre	1.000	0.130	0.045	Autonomy-Post	1.000	-0.039	0.035
Strategy-Pre	0.130	1.000	0.379*	Strategy-Post	-0.039	1.000	0.354*
Process-Pre	0.045	0.379*	1.000	Process-Post	0.035	0.354*	1.000

Table 4: Correlations between Dimensions (* = significant at p < .05)

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 is an "understander" who puts at least partial responsibility for her learning on the teacher:

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

S724, Post-test: Disagree. Memorizing facts is not better than understanding because I eventually forget the facts while when I understand it I won't forget it.

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

S724, Post-test: No. Because everyone learns things in different ways and some people teach things different than other teachers.

Conversely, students can be very 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.

Relationships between 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 dimension are highly correlated (p < .0001) at both the pre-test and post-test windows (unlike Autonomy and Process, which are not correlated). (Again, see Table 2 for descriptive statistics and Table 4 for correlations.) This finding is corroborated by the significant difference in the Process groups' Strategy mean scores (F[2, 171] = 15.938, p < .0001) and the Strategy groups' Process mean scores (F[2, 171] = 16.902, p < .0001). Another indicator of a covariance between Strategy and Process is found in the groups' change in scores. There is a significant difference between the Strategy LOW group's mean change in Process score compared to the MIDDLE and HIGH Strategy groups (Fisher's PLSD: $p < .05$); another significant difference is between the LOW and HIGH Process groups' mean change in Strategy score (Fisher's PLSD: $p < .05$).

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 hydroden 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 has 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 rationally in their approach to learning science: If one approaches science as a collection of facts, memorization is the best strategy for learning it!

How do beliefs relate to student performance?

The broad-brush representation of students would typically imply 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? Two measures of performance—grade on a large KIE project called "All The News" and grade on the final exam—are used here.

Students' pre-test scores for Strategy and Process are both highly correlated ($p < .0005$ for each dimension) with grade on the KIE project. Post-test scores for all three dimensions are highly correlated with the All The News score ($M = 81.820$, $SD = 9.541$, $N = 178$; Autonomy: $p < .05$; Strategy: $p < .0001$; Process: $p < .01$). See Table 2 for descriptive statistics and Table 5 for correlations.

	Autonomy-Pre	Autonomy-Post	Strategy-Pre	Strategy-Post	Process-Pre	Process-Post
Project Grade	0.133	0.174*	0.277*	0.310*	0.282*	0.199*
Final Exam Grade	0.043	0.131	0.163*	0.314*	0.084	0.129

Table 5: Correlations for Dimensions and Performance (* = significant at $p < .05$)

One interesting question is, did students' beliefs change in part because of participating in the All The News project, or had their beliefs already changed by the time they got to the project? We cannot ascribe full credit for the improvement in beliefs to the All The News project, but it is likely that the four KIE projects students participated in over the course of the semester did have a positive effect on students' beliefs. One student (whose Autonomy and Strategy scores both went up between the pre- and post-tests, and whose Process score remained the same) mentions two KIE projects explicitly, in conjunction with some CLP labs, as backing for the belief that ideas in science connect to one another:

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

> S428, Post-test: Agree. I think that most of the small labs like pulsing, potato and cokes, and [a project like] all the news connect with a big project like houses in the desert.

The relationship between students' beliefs and their final exam grade is more straightforward (see Table 5 for correlations). While the post-test Autonomy and Process scores are slightly positively correlated with the final exam grade ($p < .1$ in both cases), it is students' beliefs about effective learning strategies that has the most impact. Both the pre- and post-test scores for Strategy are significantly positively correlated with final exam grade ($M = 72.957$, $SD = 18.047$, $N = 174$; pre-: $p < .05$; post-: $p < .0001$). This indicates that people 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 summarizes 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 infromation to alter to make it fit your situation.

One note about student performance: Students' grades on the KIE project and final exam were highly correlated ($R = 0.289$, $p < .0001$). This provides corroboration for the intuition that good students tend to be consistent in their high performance.

How do males' and females' epistemological beliefs compare?

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?

Gender and the Nature of Learning

Girls have a slightly lower mean Autonomy pre-test score than boys do ($t[172] = -1.764$, $p = .08 < .1$). Comparing groups based on students' Autonomy pre-test scores shows us where the differences lie. A chi-square analysis indicates that there exists a significant difference in the proportions of boys and girls in the three groups ($\chi^2[2, N = 174] = 7.802$, $p < .05$). While approximately the same proportion of boys and girls fall in the least autonomous group, significantly more boys are in the highly autonomous group. (See Table 6.)

	LOW Autonomy	MIDDLE Autonomy	HIGH Autonomy	total (N)
Females	29%	63%	9%	94
Males	27%	50%	24%	80

Table 6: Boys' and girls' Autonomy beliefs, by pre-test scores

By the end of the semester, the slight difference between boys' and girls' Autonomy scores has disappeared. Both boys and girls improve in autonomy, with girls making larger gains than boys.

Students' views of Strategy are highly correlated with their performance in class. Happily, there are no significant differences between boys' and girls' views of Strategy. Girls' beliefs scores are slightly higher at both the beginning and end of the semester, with boys improving slightly more than girls over the course of the semester.

Gender and the Nature of Science

Girls have a slightly higher mean Process pre-test score than boys do (t[172] = 1.852, p = .07 < .1). A chi-square analysis indicates that there exists a significant difference in the proportions of boys and girls in the three Process groups (χ^2[2, N = 174] =7.542, p < .05). (See Table 7.)

	LOW Process	MIDDLE Process	HIGH Process	total (N)
Females	22%	41%	36%	94
Males	29%	54%	18%	80

Table 7: Boys' and girls' Process beliefs, by pre-test scores

By the end of the semester, the slight difference between boys' and girls' Process scores has disappeared. Both boys and girls improve in their views of the process of science, with boys making larger gains than girls.

Gender and Performance

No significant differences exist between boys and girls in either the All The News project or the final exam grade.

Discussion

We have seen various relationships among the beliefs dimensions and other variables like grades and gender. 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 does not support 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, Leach, Millar, & Scott, 1996), and may apply that orientation to themselves and to scientists. Further research is necessary to determine if this new hypothesis is true.

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. Remember that while Autonomy post-test scores were positively correlated with the KIE project grade, Autonomy scores were not linked with final exam scores. 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.

Why do students' beliefs about Autonomy and Strategy become more productive over time, but beliefs about Process do not?

Given the different influences on why a student might develop certain beliefs, it makes sense that those beliefs would change at different rates and at different times. Why do the students in the CLP/KIE classroom become significantly more productive in their views of Autonomy and Strategy but change only slightly in their Process scores?

The teacher in these students' classroom has claimed for years that the primary benefit of using these innovative technologies is that they allow him to concentrate, with small groups of students, on the conceptual ideas at hand rather than on logistical issues and classroom management. The technology might help students learn how to be autonomous, through providing scaffolding for completing labs and projects without the teacher's constant instruction. This autonomy may develop in two ways. First, students may become logistically autonomous, able to set up an experiment, use the technology, work at their own pace, and so on. More importantly, students may learn how to be cognitively autonomous, better able to think on their own and with peers and the teacher rather than depending on others to provide an answer. Aspects of the curriculum, including reflective prompts (Davis, 1996), further this emphasis on cognitive autonomy.

The CLP and KIE curricula may simultaneously encourage a strategy of understanding. At no point during the semester-long curriculum do the students memorize anything. They do experiments and projects in which they develop scientific principles and apply those principles to explain scientific phenomena. The greatest overall dimension gain, in fact, occurred for the Strategy dimension, indicating perhaps that the curriculum had the greatest effect on this particular dimension.

The curriculum attempts to encourage a view of science that is dynamic, as well. Students doing KIE projects use evidence to support their decisions, and students doing CLP labs are experimenting, sharing data, and drawing conclusions much as scientists do. Why do their Process scores not change much?

One hypothesis is that the curriculum does not encourage the dynamic view intended. In fact, although a goal of the curriculum is to model the dynamic nature of science, any school curriculum is necessarily limited in what it can do to achieve this goal. A second, related hypothesis is that beliefs about the process of scientific inquiry are more difficult to change. A third hypothesis is that eighth graders may not care as much about the nature of science as they might. At age 13, kids are often thinking about any number of things other than science. One last hypothesis is the existence of a ceiling effect. Some students may have "topped out" on their view of scientific decision-making before even entering the class. Further research is necessary to determine why students' Process views do not change as much as the other dimensions, and to develop appropriate instructional interventions to improve the situation.

Why do the beliefs of students who start out with less productive beliefs become more productive?

Educators are generally pleased by improvements and disappointed by declines in scores. Often (especially in the case of improvements) we do not take the time to discover if all students are changing in the same direction and to the same degree, or if different groups are behaving differently. As the analysis presented earlier indicates, it is sometimes quite important to go that extra step.

Why did the students whose pre-test scores were low change in a positive direction much more than the other students? Why did the beliefs of students with high pre-test scores, in fact, become less productive? One likely hypothesis is a simple regression to the mean. Another possibility is that, through working with other students on labs and projects, students were exposed to ideas different from their own. Naturally, all students would adopt some of these different ideas—regardless of their inherent productivity or lack thereof. A third hypothesis is that an innovative curriculum like this one is of the most benefit to students who have, for whatever reasons, developed the least productive beliefs about science and learning up till this point. Further research is necessary to investigate ways of helping all students develop more productive beliefs.

Why are several dimensions related to success on a large project but only Strategy is related to success on final?

Because of the emphasis on explanation, application, and understanding in the curriculum, it is not surprising that the Strategy dimension would be positively correlated with the final exam grade. If one adopts a strategy of understanding, one is more likely to perform well on a test designed to measure understanding. (Further research will investigate the relationship between beliefs and knowledge integration more deeply.) Why, though, do students with productive beliefs about all three dimensions tend to do well on a large project?

A project like All The News requires conceptual understanding, but it also requires much more than that. Students need to be able to write well, to manage their time, to follow instructions to achieve their goals—all the kinds of skills required in the real world. While a good grasp of the science concepts will earn points in this circumstance, so will several other skills or traits. Thus, very different students are likely to succeed on a project like this one. In addition, students typically work in pairs on KIE projects. Thus, a pair's grade is influenced by the knowledge and skills two people bring to the task, rather than one.

Why might specific beliefs be of benefit? KIE projects are built on the premise of explaining scientific phenomena using evidence. The All The News project in particular emphasizes critiquing evidence. Highly autonomous students may have developed the ability to critique or may be more likely to see the benefit of doing so. They may thus tend to succeed on the project more than less autonomous students. Furthermore, students who perceive understanding as a good strategy are more likely to perform well on an assessment based in part on the demonstration of conceptual understanding. And, a student with a belief in the dynamic nature of the scientific process might see KIE projects as authentic, and thus be more engaged than other students who see it as a meaningless exercise. Alternatively, a dynamic view of science may help students understand that explanation-giving is important in science, and they may then be more likely to give the explanations vital for success on the project. Interestingly, related work by Bell (1997) indicates that students' views of the Process of science are predictive of their scientific argumentation skills.

Implications and Conclusions

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.

There were greater gains over the course of the semester in the Strategy dimension than in the other dimensions. Innovative teaching may particularly help students make gains in their views of appropriate learning strategies—that is, teaching that emphasizes understanding, application, and explanation 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. Furthermore, the beliefs of students who started out with less productive beliefs changed 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 does not support 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. It may be true that once students identify the concept of "sense-making" and add it to their repertoire of ideas, they will 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. More students are also able to succeed on large projects because their own expertise is likely to be of benefit. Such projects provide another avenue for achieving the kinds of innovation likely to benefit students. 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.

Finally, although autonomy is not necessarily rewarded by all aspects of middle school curricula, it is a skill lifelong learners need. Therefore, instruction should encourage autonomy. In the CLP/KIE classroom, technology scaffolds students to allow them to be autonomous without flailing. Furthermore, innovations such as reflective prompts model expert reflection processes to facilitate students' autonomous knowledge integration (Davis, 1996).

Students exhibit various beliefs about the nature of science and the nature of learning science. Those beliefs are not consistently productive or less productive, but are linked in interesting ways. Although we do not yet understand the causal relationships among beliefs and performance, it is clear that modeling more productive beliefs for students in many different ways is likely to help them improve not just in their beliefs about science and learning science, but also in their level of conceptual understanding of science.

Appendix: Relevant Questions on Beliefs Test

Autonomy of Learning *Items*

2. I know I understand something when... **(check all that apply)**

_______ I've studied for the test
_______ I can do the problems
_______ the teacher has explained it
_______ I've seen a demonstration of it

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

(circle one for each statement)

a. be told what is correct by a teacher.	always	sometimes	never
d. have a parent or teacher explain the right answer to me.	always	sometimes	never

Strategy for Learning *Items*

2. I know I understand something when... **(check all that apply)**
_______ I can apply it to a new situation
_______ I can explain it to someone else
_______ I can imagine how it works

4a. "When understanding new ideas in science class, memorizing facts is better than trying to understand complicated material." **(circle one)** **Agree** **Disagree**

6a. "I expect most of the ideas in science class to connect to a few big ideas."

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

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

(circle one for each statement)

b. use what I already know.	always	sometimes	never
f. ignore the ideas that don't make sense	always	sometimes	never
g. use an example to help me understand.	always	sometimes	never
h. connect the new ideas to my past experiences.	always	sometimes	never
i. read the right answers in the textbook.	always	sometimes	never

Process of Scientific Inquiry *Items*

7a. "The science principles in textbooks will always be true."

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

10a. While in Antarctica, a scientist found a meteorite from Mars. Using the meteorite as evidence, a few scientists recently made an argument that there was once life on Mars. Based on previous scientific ideas and evidence, however, another group of scientists don't think that the meteorite is evidence of life on Mars.

Why do you think these scientists are arguing? **(check all that apply)**

_______ they are all trying to understand the meteorite evidence better

_______ they are trying to see how the meteorite evidence fits with other things they know

_______ one group must not be willing to consider the ideas of the other group

13. What would you like to **learn more about** in your science classes?
(check all that apply)

_______ How to fix things or cure people

_______ How scientists discover things

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