COGNITION AND INSTRUCTION, *15*(1), 1–40

Knowledge Building as a Mediator of Conflict in Conceptual Change

Carol Chan
Faculty of Education
University of Hong Kong

Jud Burtis and Carl Bereiter
Centre for Applied Cognitive Science
Ontario Institute for Studies in Education
of the University of Toronto

This study examined how individuals and peers process scientific information that contradicts what they believe and assessed the contribution of this activity to conceptual change. Participants included 54 students in Grade 9 and 54 students in Grade 12, who were randomly assigned to four conditions: (a) individual conflict, (b) peer conflict, (c) individual assimilation, and (d) peer assimilation. Depending on the condition, students were asked to think aloud or discuss with their peers eight scientifically valid statements, which were presented in an order that either maximized or minimized the conflict between new information and existing beliefs. Pretest and posttest measures of prior knowledge and conceptual change were obtained, and student verbalizations were tape-recorded and coded for five levels of knowledge-processing activity. Two major approaches were identified from this analysis: *direct assimilation,* which involved fitting new information with what was already known, and *knowledge building,* which involved treating new information as something problematic that needed to be explained. A path analysis indicated that the level of knowledge-processing activity exerted a direct effect on conceptual change and that this activity mediated the effect of conflict. Knowledge building as a mediator of conflict in conceptual change helps to explicate previous equivocal research findings and highlights the importance of students' constructive activity in learning.

Requests for reprints should be sent to Jud Burtis, Ontario Institute for Studies in Education of the University of Toronto, 252 Bloor Street West, Toronto, Ontario, Canada M5S 1V6.

Cognitive research has shown the pervasive role of prior knowledge in understanding and problem solving (Chi & Ceci, 1987; Chi, Glaser, & Farr, 1988; Glaser, 1984; Glaser & Bassok, 1989). The importance of prior knowledge is also reflected in another strand of research. In the last two decades, substantial evidence has accumulated that shows the broad range of naive conceptions students bring to the interpretation of phenomena (Driver, Guesne, & Tiberghien, 1985; Eylon & Linn, 1988; Pfundt & Duit, 1994). These alternative conceptions, sometimes called misconceptions because they are different from what is scientifically accepted, have been shown to be robust and resistant.

A common approach to fostering conceptual change is based on a conceptual-conflict strategy (Posner, Strike, Hewson, & Gertzog, 1982; West & Pines, 1985). This instructional approach involves identifying students' current state of knowledge and bringing about confrontation so that students replace their preexisting ideas with scientifically accepted ones. Within the conceptual-conflict paradigm, refutation texts have been designed to help students overcome their naive conceptions (for a meta-analysis, see Guzzetti & Glass, 1993). Despite much enthusiasm for a conceptual-conflict approach, findings have been equivocal. Even when students are confronted with contradictory information, they are often unable to achieve meaningful conflict or to become dissatisfied with their prior conceptions (Alvermann & Hague, 1989; Champagne, Gunstone, & Klopfer, 1985; Dreyfus, Jungwirth, & Eliovitch, 1990; Eylon & Linn, 1988; Guzzetti, 1990; Guzzetti & Glass, 1993; Hewson & Thorley, 1989; Hynd & Alvermann, 1989; Maria & MacGinitie, 1987; Wang & Andre, 1991; West & Pines, 1985).

From science education to cognition, there is now increased emphasis on students' meaningful understanding of science. Researchers have commonly agreed that it is inadequate to catalogue misconceptions; rather, there is a need to examine knowledge restructuring (Duschl & Gitomer, 1991; Eylon & Linn, 1988; Linn & Songer, 1991) because science learning is seen as actively constructed (Osborne & Wittrock, 1983). Different ideas such as epistemological beliefs (Qian & Alvermann, 1995), sense making (Anderson & Roth, 1989), belief revision (Schauble, 1990), explanation (Bielaczyc, Pirolli, & Brown, 1995), dialectical processes (Klahr & Dunbar, 1988), and self-explanation (Chi, de Leeuw, Chiu, & LaVancher, 1994) suggest the importance of students' active, constructive roles in science learning.

A major research theme in instructional psychology emphasizes students' self-regulatory strategy in their own learning (Bereiter & Scardamalia, 1992; Glaser & Bassok, 1989; Resnick, 1989). Theoretical notions such as surface-deep (Biggs, 1984), mindfulness (Salomon & Globerson, 1987), explanation (Bielaczyc et al., 1995), and intentional learning (Bereiter & Scardamalia, 1989) have been used to characterize the distinction between a passive versus an active approach to learning. Whereas earlier research was concerned with content-free, self-monitoring skills (Brown, 1980; Markman, 1981) and comprehension strategies (Bereiter & Bird, 1985; Palincsar & Brown, 1984), recognition of the importance of prior knowledge (Chi et al., 1988; Glaser, 1984) has led to increased interest in the role of students' self-regulatory strategy in fostering meaningful understanding of a coherent body of knowledge (Bereiter & Scardamalia, 1992; Glaser & Bassok, 1989).

The idea of students' self-regulatory learning in fostering knowledge construction is particularly interesting in the context of conceptual change. Research in reading (Scardamalia & Bereiter, 1984), writing (Scardamalia & Bereiter, 1987), and intentional learning (Bereiter & Scardamalia, 1989; Chan, Burtis, Scardamalia, & Bereiter, 1992) has shown the importance of a problem-centered approach to learning. Two contrasting approaches to understanding new concepts in unfamiliar domains have been identified: *Direct assimilation* involves fitting new information directly into existing knowledge, whereas *knowledge building* involves learners treating new concepts as something problematic that they need to explain (Bereiter & Scardamalia, 1993).

It is proposed here that the contrasting approaches of direct assimilation and knowledge building provide a useful framework for examining the persistence of naive conceptions and the acquisition of conceptual change. Such conceptions tend to persist, it is argued, because students process new information by directly assimilating it into their existing knowledge, often based on everyday experience. For example, in learning about plant nutrition, students who interpret new information by immediately fitting it into their existing understanding of animal nutrition are likely to misunderstand the new information. Alternatively, students who use a knowledge-building approach—setting up pointers to difficult concepts, questioning whether familiar words have the same meaning in the new domain, constructing explanations to resolve the discrepancies, and wondering what there is to learn—are more likely to experience conceptual change.

Current theories of conceptual change have focused on examining the qualitative nature of naive concepts (e.g., see Resnick, 1993). Considerable controversy exists with regard to whether naive concepts are coherent or fragmentary. Although acknowledging the current debate, this study was aimed at examining conceptual change from the perspective of students' constructive activity. From a pedagogical perspective, how students approach the learning situation is important because, whether naive concepts are stable or fragmentary, students themselves need to revamp their models or work at constructing a coherent network of knowledge.

The role of knowledge-building activity in fostering science learning also seems consistent with current theories on conceptual change as involving knowledge restructuring (Chi, Slotta, & de Leeuw, 1994). These researchers argued that conceptual change is difficult because it may involve a radical shift across ontologically incompatible categories (Chi, Slotta, et al., 1994). Although it is unclear as to which specific kinds of science concepts involve radical restructuring, a knowledge-building approach would seem beneficial for the learning of difficult concepts. Instead of directly assimilating new concepts, students employing knowledge-building activity are more likely to delay immediate interpretation, to recognize the difficulties of the new concepts, and to avoid equating ontologically incompatible new concepts with their prior conceptions.

The goal of this study was to examine how students construct scientific understanding when confronted with information that contradicts what they believe. Specifically, the first objective was to identify the kinds of knowledge-processing activity students engage in when they are learning from scientific information and to assess the effects of such activity on conceptual change. Extending research on students' constructive processes in comprehension (Scardamalia & Bereiter, 1984) and learning from text (Chan et al., 1992), this study examined how students process text statements that contradict what they believe in the domain of biological evolution.

Students' knowledge-processing activity was assessed based on their verbalization in response to the contradictory text statements. Consistent with research on students' constructive activity (Chan et al., 1992), it was hypothesized that older students would engage in more sophisticated knowledge-building activity than younger students. It was also predicted that students employing a knowledge-building approach would perform better than students employing a direct-assimilation approach on conceptual-change measures.

The second objective was to assess the efficacy of conflictual information and to examine its relations with a knowledge-building approach to learning. Thus far, equivocal findings have been obtained in using a conceptual-conflict approach to fostering conceptual change. It has been argued that students themselves have to become dissatisfied with their prior conceptions (Hewson & Thorley, 1989). When confronted with anomalous information, students often use coping tactics (Chinn & Brewer, 1993) and assimilate rather than accommodate their schemata to make sense of the information (Lipson, 1982; Maria & MacGinitie, 1982). On the other hand, students' use of constructive activity such as conceptual-processing strategies fosters understanding of refutation texts (Anderson & Roth, 1989) and mediates the effects of prior knowledge on new learning (Chan et al., 1992). Accordingly, it is proposed that the way students approach their learning would affect how they process the conflictual information and subsequent conceptual change.

Previous research has examined the effects of conceptual conflict based on comparisons of group differences (for a meta-analysis, see Guzetti & Glass, 1993). In order to investigate the relations between conflict and knowledge-building activity in this study, individual differences in how students responded to new information were tracked. A computer-based connectionist methodology was developed to allow the experimenter to identify the degree of conflict between a given text statement and a student's expressed beliefs. Conflict was compared on the basis of two conditions in which new text statement information was presented to maximize or minimize the conflict with each student's beliefs. It was hypothesized that the more conflictual condition would be related to more conceptual change but that this effect would be mediated by the amount of knowledge-processing activity engaged in by the student.

A third objective was to investigate the role of peer interaction in conceptual change by examining how pairs of students learn from incompatible information. Although peer learning has been shown to be effective in promoting text comprehension (Brown & Palincsar, 1989), much less is known about how students jointly process information that is incompatible with their prior knowledge. Research has shown that conceptual change is related to destabilization of familiar procedures (Amigues, 1988) and productive discourse as students construct their convergent understanding (Roschelle, 1992). It would seem that peer collaboration may discourage direct assimilation as students are given the opportunity to examine each other's ideas. In addition, contradictory information may provoke students to identify different viewpoints and to engage in deeper inquiry.

This study investigated the effects of peer collaboration on conceptual change by comparing two conditions: Students were asked either to work on their own or to negotiate their understanding with their peers when confronted with contradictory information. It was predicted that students in the peer condition would engage in more knowledge-processing activity and would show more conceptual change than students in the individual condition.

In summary, this study examined knowledge construction in the context of how individuals and peers process new information incompatible with their beliefs. Three research questions were addressed: (a) Do the hypothesized approaches of direct assimilation and knowledge building differentially affect conceptual change? (b) Does conflict lead to more conceptual change, and are its effects mediated by knowledge-processing activity? and (c) Does peer collaboration foster conceptual change when students are confronted with contradictory information?

METHOD

Overview

The study consisted of two phases. Phase 1 was a preliminary investigation to identify students' naive conceptions of evolution and to develop materials necessary for the connectionist methodology of Phase 2. Phase 2 was the main investigation, which was a conceptual-change experiment in which students were individually presented with materials derived from Phase 1 that contradicted their current conceptions of evolution and were asked to respond to the contradictory information.

Phase 1—Identifying Preinstructional Conceptions

A questionnaire consisting of 49 statements representing various accurate and inaccurate conceptions of evolution was constructed. The statements were based on existing research into students' conceptions of evolution and extensively field-tested with students and biology teachers. Pilot work, including a factor analysis of student responses, had suggested that student conceptions of evolution could be represented by four factors: (a) Purpose, (b) Battle, (c) Environmental Change, and (d) Darwinism. The questionnaire included 11 to 13 items for each of these four factors. Students' naive conceptions identified in the factor-analytic study were consistent with earlier descriptive studies (Bishop & Anderson, 1990; Brumby, 1984; Deadman & Kelly, 1978) and with more recent findings on explanations in evolution (Ohlsson, 1991).

For each factor, "false" items were constructed to represent naive conceptions, and "true" items were constructed to represent scientific information that contradicted the naive conceptions. For example, for Factor 1 (Purpose), a test item that said "Animals do not change unnecessarily. They only change when needs arise" was constructed to reflect the naive belief that evolution is purposeful. This item was considered a false statement. Conversely, an item that said "New characteristics first arise by chance, not by needs" was considered true because it reflected scientific information that directly contradicts the naive conception.

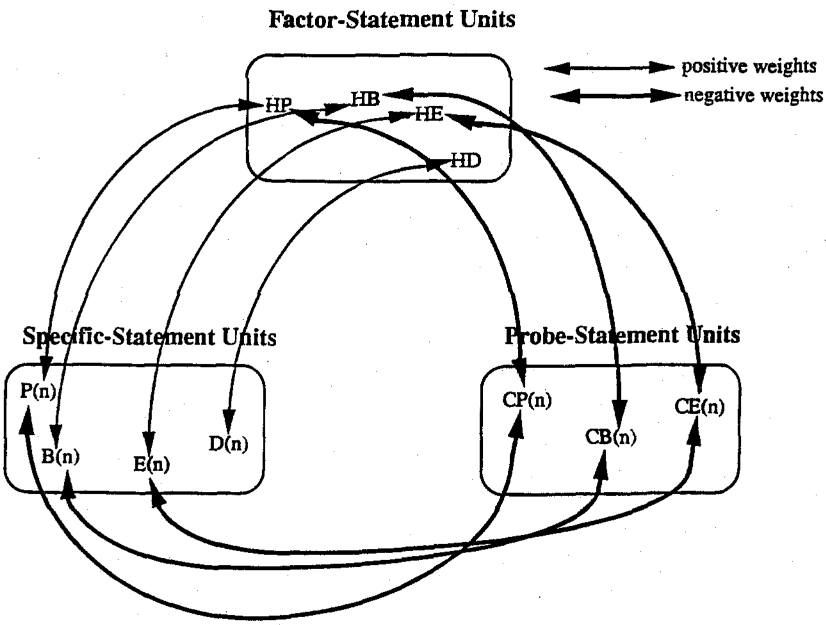
No absolute true or false status was ascribed to these items. Because the objective of this preliminary investigation was to develop test materials that reflected or contradicted students' naive conceptions, these items were only provisionally called true or false for experimental purposes.

The questionnaire was administered to 190 students in Grades 9 to 13. Students were asked to indicate whether they agreed or disagreed with each statement on a 5-point scale. Factor analysis on the student responses yielded a four-factor solution that corresponded very closely to the four factors used to construct the scales. The internal consistency of the scales was estimated using Cronbach's alpha, and the coefficients were .76 (Purpose), .71 (Darwinism), .65 (Environmental Change), and .61 (Battle). Two biology teachers were asked to fill out the questionnaire to provide reliability data. The interrater reliability of the experts' rating was .80 (Pearson correlation).

Phase 2—Confronting Prior Conceptions With Scientific Information

The connectionist methodology. A computer-based connectionist methodology was developed to provide a principled way to present students with new information at different degrees of discrepancy from their existing beliefs. The basic design involved setting up a network based on the Interactive Activation and Competition (IAC) program (Rumelhart, McClelland, & the PDP Research Group, 1986). This study did not intend to test a connectionist view of thinking; the connectionist program was employed merely as a tool for assessing students' prior conceptions and for selecting text statements that either matched or contradicted those conceptions.

Figure 1 shows how the connectionist network was set up. Selected items from the factor-analytic study of Phase 1 were given a set of weighted connections to each other and to the four identified factors. Three groups of units were included in the network: (a) four *factor-statement* units, which were units derived from the



Units	**Examples**
Factor Statements HP, HB, HE, HD.	HP: Evolution is directed by need and purposes of animal species.
Specific Statements P1, P2, B1, B2, E1, E2, D1, D2.	P1: Animals do not change unnecessarily. They only change when needs arise.
Probe Statements CP1, CP2, CPE CE1, CE2, CB1 CB2, AP.	CP1: An animal cannot evolve by adapting to its environment. It is the environment which selects the well-adapted animals.

FIGURE 1 Connections among the three groups of units in the connectionist network.

four factors of the factor-analytic study and represented the four major conceptions of evolution; (b) eight *specific-statement* units, which were questionnaire items from the factor-analytic study that had substantial positive loadings on the four factors; and (c) eight *probe-statement* units, which were questionnaire items from the factor-analytic study that had substantial negative loadings on the four factors, that is, they were questionnaire items consisting of information that contradicted the naive conceptions. (These statements are hereafter referred to as the *factor statements,* the *specific statements,* and the *probe statements.*) In the IAC program, when some of the units receive external inputs, all of the units in the connectionist network are activated. The degree of activation varies according to the strength of the external inputs and the strength of the connections among the units.

In this experiment, a given student's ratings of the importance of the four factor statements in explaining evolution were entered as inputs. These indicated the student's conception of evolution. The outputs were the activation levels of the eight probe statements: scientifically valid statements that tended to contradict naive conceptions. The more positive the activation level of a probe statement, the more compatible it was taken to be with the student's own position; the more negative the activation, the more incompatible. Activation of the network thereby allowed a student's patterns of agreement or disagreement to the factor statements to be used to identify whether he or she would agree with the probe statements. Accordingly, the experimenter could systematically provide the student with a probe statement that was, in varying degrees, congruent or contradictory to the student's beliefs.

When a probe statement was presented by the experimenter, it consisted of the original test item followed by an elaborative statement, as shown in the Appendix. Fine tuning and field testing were conducted to ensure that the program behaved appropriately. For example, a high input to a "purpose" misconception factor statement should lead to high negative activation levels for the "antipurpose" probe statements. The program was installed on a laptop computer equipped with a math coprocessor, which allowed the IAC program to be run online during testing.

Participants

Participants included 108 students: 54 from Grade 9 and 54 from Grades 12 to 13 from a high school in suburban Toronto. Students represented a range of abilities for their grade level. Most had no formal instruction in evolution because this curriculum unit is taught to Grade 13 biology students in the spring semester, and testing was carried out in the fall. Students holding a creationist view of evolution, as determined by the pretest, were excluded from the study.

Conditions

Students were randomly assigned to one of the four conditions: (a) individual assimilation, (b) individual conflict, (c) peer assimilation, and (d) peer conflict. The procedure for each condition is described next.

Procedure

Pretest

Students in the two individual conditions (individual assimilation and individual conflict) were individually interviewed by an experimenter and asked (a) to tell what they knew about evolution of animal species, (b) to indicate whether they agreed or disagreed with the eight specific statements on an 11-point scale, and (c) to rate on an 11-point scale the relative importance of the four factor statements in explaining evolution. Students in the two peer conditions (peer assimilation and peer conflict) were interviewed individually for the first two tasks and worked with their pair-mates in the third task to decide on the ratings for the four factor statements.

Experiment

Students' ratings of the four factor statements were entered as inputs to the IAC network, whose outputs were activation levels on the eight probe statements. In the assimilation conditions, students were then presented with the probe statement that was maximally congruent with their understanding of evolution, as determined by the IAC network. In the conflict conditions, students were presented with the probe statement that maximally contradicted their understanding. In either case, students were told that the probe statement they were given was generally accepted by scientists and that they were to read it and learn something about evolution based on it. When the student had read the probe statement, the experimenter asked, "What does this make you think about evolution?"

After the first probe statement was presented, students were given the opportunity to rerate the four factor statements. Students in the peer conditions had to decide jointly on any changes in their ratings. Students were told that they were not required to make changes, and it was up to them to decide whether any revision of ratings was necessary. If no changes were made, the next maximally discrepant or maximally congruent probe statement was presented depending on condition. If any changes were made, the new ratings were entered into the computer-based network, and new activation levels were obtained for the remaining probe statements. The same procedure was followed until all eight probe statements had been presented. Students' verbalizations were tape-recorded for subsequent analysis.

Posttest

Students' learning was assessed by asking them to rerate the four factor statements one final time. Again, in the peer condition, the two students in a pair had to negotiate and come to consensus in their ratings. Students in all conditions were then assessed individually and were asked (a) to summarize their present understanding of evolution; (b) to tell what else they did not understand about evolution; (c) to respond to a near-application question, which was to explain how ducks evolved webbed feet; (d) to respond to a far-application question, which was to explain why insecticides are no longer effective after repeated use; and (e) to rerate the eight specific statements.

Measures

Pretest Measures

Prior knowledge. A 3-point scale was developed for rating students' pretest verbalizations of what they already knew about evolution. Responses consisting of intuitive conceptions were rated 1, responses that included some impoverished understanding of genetic variation were rated 2, and responses indicating an understanding of the Darwinian conception were rated 3. A second rater scored a random set of 35 protocols. Interrater reliability was .94 (Pearson correlation), with 92% agreement.

Specific-statement ratings. Students were asked to indicate on an 11-point scale whether they agreed or disagreed with the eight specific statements about evolution (see the Appendix). A criterion measure was constructed as the average rating of two experts, and correlation between each student's ratings and the criterion over the eight items was computed to provide a measure of prior knowledge.

Factor-statement ratings. Students were asked to indicate on an 11-point scale the relative importance of the four factor statements in explaining evolution (see the Appendix). Ratings from three experts (biology teachers) were obtained and averaged to provide a criterion measure. Correlations between students' ratings and this criterion were computed. This was the only negotiated score and was identical for both students in the dyads.

The Knowledge-Processing Activity Scale

Students' verbal responses to the probe statements were coded on a 5-point scale to distinguish different levels of knowledge-processing activity. The present rating scale was developed based on earlier scales of constructive activity (Chan et al., 1992; Scardamalia & Bereiter, 1984). Instead of identifying several dimensions and rating student responses based on these criteria, we derived prototypical examples of knowledge-processing activity by examining student responses. The scale was developed by grouping the observed responses into five levels of complexity and then defining each level both theoretically and through examples. After the scale had been defined, an independent rater rated a portion of the protocols to establish reliability.

The scale distinguishes five levels of knowledge-processing activity (Table 1). In order to orient the rater to the characteristics of responses at each level, finer distinctions are also made at each level, but these do not receive different scores. The scale does not attempt to describe every possible think-aloud response. Rather, it seeks to establish clear prototypes for each level and relies on the judgment of the rater to decide with which prototype a new response is most similar.

Level 1—Subassimilation. A rating of 1 was assigned to responses remotely related to the text information, cued by isolated words or phrases. For example, one probe statement said:

> An animal cannot evolve by adapting to its environment. It is the environment which selects the well-adapted animals. A deer cannot choose to evolve long legs although long legs are important for survival. Some deer, however, may be born with longer legs which allow them to run faster. These individuals have a better chance of surviving and leave more offspring.

To that statement, one student responded:

> I think the smaller you are, the faster you can go, like your strides are smaller. ... Giraffes have long legs and they have to take bigger strides to keep their pace going. I know that because I am tall, I have to take bigger strides, and it slows me down. ... But I think the smaller the animals, the faster they go.

This response consists of associative comments to the text fragment "long legs" but does not deal with what the text says about evolution. Level 1 responses are subassimilative because they are irrelevant to the point of the text and fall short of assimilating new information into one's existing beliefs.

TABLE 1
The Knowledge-Processing Activity Scale

Rating	*General Description*	*Specific Knowledge-Processing Activity*
1	Subassimilation: New information is reacted to at an associative level	Off-text association: Gives associative responses remotely related to texts cued by salient surface features
2	Direct assimilation: New information is either assimilated as if it was something already known or excluded if it does not fit with prior beliefs	Stonewalling: Ignores, excludes, and denies new information and retells one's beliefs Distortion: Twists, distorts, and overinterprets new information to make it fit with prior beliefs Patching: Notices surface discrepancy and patches the differences by ad hoc rationalizations
3	Surface-constructive: New information is comprehended, but its implications for one's beliefs are not considered	Paraphrases/inferences: Paraphrases, makes simple text inferences, and asks text-related questions with no attempt to make belief revision Juxtaposition: Attends to text information but places new ideas alongside existing naive ideas with no integration Exception: Attends to text information but new idea is considered an exceptional case with no need for belief revision
4	Implicit knowledge building: New information is treated as something problematic that needs explaining	Problem recognition: Identifies conflict and recognizes new information as something different from one's beliefs Explanation-driven inquiry: Identifies inconsistencies and constructs explanations to reconcile knowledge conflict
5	Explicit knowledge building: New information is accumulated for constructing coherence in domain understanding	Coherence: Halts immediate interpretation and seeks connections among diverse pieces of information Model comparisons: Identifies conflicting hypotheses for explaining the domain in question

Level 2—Direct assimilation. A rating of 2 was assigned to responses that involved fitting new information directly into students' existing knowledge concepts. Three kinds of assimilative responses were identified: (a) stonewalling, (b) distortion, and (c) patching.

- *Stonewalling:* The student ignores, denies, and excludes new information that differs from his or her beliefs. Instead of attending to what is said, the student refuses to respond to the new information but merely reiterates what he or she already knows. For example, one student said:

> I don't agree with that because they [animals] are adapting to their environment. The squirrels and everything you see in the street are cautious about crossing the street. Of course, they have adapted to the environment, and they have to. They must have done it for years now and passed it on to their offspring.

- *Distortion:* The student distorts and twists the text information to make it fit with prior beliefs. Typically, the student attends only to the salient features of the statement and makes overextended interpretation, conflating his or her beliefs with the contradictory new information. An example of distortion is the following: "I agree this is correct. It is true that an animal cannot choose to adapt itself to the environment; the environment has to adapt to you basically. The environment has to be suitable for you in order to live."
- *Patching:* The student accepts the conflictual information at face value and patches the differences by ad hoc rationalizations. In response to the probe statement, a student said:

> I guess it is pretty true. I forgot to think about that. That if an animal can't survive, it will move to a new environment where it can. Because I just realized that, if a polar bear lived in the tropics, or a deer lived on an ice cap, they'd try to get to colder and warmer climates, respectively.

The first response—stonewalling—suggests that the contradictory information was simply ignored by the student. Instead of considering the new evidence (selection of long-legged deer), the student did not refer to what was presented; he simply denied the new information, reacted to a fragmentary part of the statement, and reiterated something that he already knew. The second response—distortion—was somewhat interesting because new information was accepted, even though it actually contradicted what the student believed. In this case, the student seemed to be attending only to the salient features of the text that fit with his beliefs (animals cannot choose); environmental selection was distorted to mean environmental suitability. Instead of rejecting or ignoring the discrepancy, the student who gave the third response patched the difference by coming up with an idiosyncratic justification: Animals move away from unsuitable environments. It could then be said that although animals could not adapt to their environment, they could move away. Hence, the student's core belief in need-initiated change could remain intact.

Stonewalling, distortion, and patching are somewhat different but are related: They reflect assimilative activity because they suggest the predominant role of preexisting beliefs in excluding new information that does not fit. For stonewalling, the student keeps his or her beliefs intact by ignoring or refusing to deal with the new information. For distortion, the student twists the new information in ways that make it fit better with his or her schema. Patching, on the other hand, involves some kind of melding between new information and prior conceptions so that no knowledge restructuring is required. Assimilative activity preserves a student's naive beliefs but minimizes the opportunity for knowledge restructuring.

Level 3—Surface constructive. A rating of 3 was assigned to responses that provided evidence of text comprehension. Text information is attended to, but its implications for one's beliefs are not considered.

- *Paraphrases:* The student gives simple paraphrases or makes local inferences of the new information. For example, one student said, "I guess long legs helps reproduction because they run faster, they survive, and leave more offspring. It is not the deer's choice whether it has long legs or not. It just happens."
- *Juxtaposition:* The student recognizes the discrepancy between his or her naive conceptions and the text, but the inconsistency is minimized by juxtaposing correct and incorrect information. To a probe statement that "evolution occurred first by chance, not by needs," one student said:

> I thought if they needed it, they get it, and if they don't, they don't get it. ... It changes two of these cards. But I still think it developed by needs a little bit, and I am not quite certain it develops by chance most of the time, so I am gonna put it 60/40.

- *Exception:* The student comprehends some new idea but minimizes the problem of weighing it against his or her beliefs by using an exception strategy. For example, to the probe statement about black moths outnumbering white moths in polluted areas, one student said:

> That it is not animals adapting to environment in this particular case with the moths; it is mainly survival of the best. And adaptation was just because they survived better. It is very straightforward, I think, but this is one, this is only one case where this has happened.

All the preceding Level 3 responses suggest a surface approach to dealing with text information. Although the first example consisted of an inference about longer legs and higher reproduction rate, the student did not go further to consider what this inference meant in terms of evolution. The second example suggested that new and old information was juxtaposed ("I am gonna put it 60/40") without any attempt to explain how things really work. Similarly, the third example showed that the student might have understood what the text says (survival of the fittest), but instead of examining the generality of the principle, the situation was considered an exceptional case.

Although Level 2 responses show the dismissal of text information in favor of preexisting beliefs, Level 3 responses provide evidence of text comprehension. There is a shift of focus from merely retelling what one already knows to examining what the text says. However, Level 3 responses fall short of Level 4 in that the implications of the new information for existing beliefs are not considered.

Level 4—Implicit knowledge building. A rating of 4 was assigned to responses that involved treating new information as something problematic and in need of attention. Two different kinds of implicit knowledge-building moves were identified: problem recognition and explanation-driven inquiry.

• *Problem recognition:* The student recognizes that a different perspective, distinct from his or her own beliefs, has been presented. For example, to a probe statement that some animals are well adapted to their environment even though they are all eaten by their predators, one student said:

> Well, it's funny, because when you think of adapting to your environment, you always think of doing something to survive. And it's funny here that it's talking about the animal in general, 'cause usually I think of each animal, like each rabbit having its own characteristics. So, when it's talking about they have to eat some rabbits in order to let the other ones survive, it's a kind of a different way of thinking.

• *Explanation-driven inquiry:* The student identifies inconsistencies and constructs explanations to reconcile the differences. An example of explanation-driven inquiry follows:

> I don't know about the leaving more offspring, but they probably have a better chance of surviving because they can outrun their predators. But an animal can't evolve by adapting? How did the deer get the long legs in the first place? Something must have told them to grow long legs ... or if it was just made with long legs in the beginning? So, it is adapting to its environment, but there is something missing; but not all animals adapt to their environment, so the ones that can adapt are the ones more likely to survive. ... It can't choose to evolve long legs, but some may be born with long legs, so maybe there's some change occurring in the deer. The way it is at birth is the way it is going to be for the rest of its life. But the way a deer evolves might not be in its lifetime but in the lifetime of its offspring.

The first Level 4 example suggests that the student recognized that a different way of thinking had been presented. Instead of eliminating conflict or merely juxtaposing new and old information, the student seemed to treat her knowledge as an object of inquiry ("you always think ... here ... it's talking"). The second example suggests that the student not only recognized a knowledge problem but also constructed explanations to reconcile the differences. Implicit knowledge-building responses involve problem-solving procedures such as identifying inconsistencies, sense-making tactics, and construction of explanations. Incompatible information is treated as something problematic that needs to be explained.

Level 5—Explicit knowledge building. A rating of 5 was assigned to responses that consisted of metacomments indicating deliberate moves to halt immediate interpretation and to make connections among diverse pieces of information.

- *Coherence construction:* The student stops from making immediate judgment and examines connections among different pieces of information. The following is an example of accumulating and seeking connections among information:

> It seems like the cards all contradict themselves. ... This card seems out of place from the others. I'm trying to piece things together into one whole, to find a connection. Right now, I'm trying to think about how everything can connect because I have to keep in mind all the other cards I have seen. ... This one is the main one, and it seems like others are less important. But we still have to give them proper standing because it still does matter.

- *Comparison of conflicting models:* The student identifies conflicting hypotheses for the domain in question. For example, one student said:

> What they are saying, first they are saying, the environment does not affect the adaptation of animals. If the animal somehow changes, then, due to its environment, it might survive. There is always this conflict of whether it is the environment or needs, and I see that scientists say it's by chance, so what do you think?

The first Level 5 response consists of an instance in which the student indicated the need to pit contradictory pieces of information against each other to construct a deeper understanding. Instead of merely working with the statement at hand, Level 5 responses involve elaborating the problem as the student spontaneously refers to earlier or yet-to-be received information. Again, in the second response, the student seemed to have elevated the problem to a different level as she pondered different hypotheses that may explain evolution. Overall, Level 5 responses involve addressing the problem of discordant pieces of information in an attempt to construct more complex knowledge.

Reliability

Verbal responses given during the experiment to each of the eight probe statements were coded based on this 5-point knowledge-processing activity scale. One statement (CP2) was excluded due to an unanticipated ambiguity in the elaborated example; ratings were therefore based on seven statements. In order to maximize independence of coding between statements from the same students, each protocol was separated into seven units, which were scored separately. Halo effects were therefore minimized by blind rating of disassembled protocols. The first author scored all the responses, and a second rater independently scored a random set of 220 responses, constituting about 30% of the entire sample. The correlation between the two raters was .85 for the individual condition and .81 for the peer condition. The reliability of the scale was also assessed by examining the internal consistency of the seven ratings given to each student. The value of Cronbach's alpha, based on the entire sample, was .79.

Posttest Measures

Knowledge quality. Three different measures were developed to assess students' posttest understanding of evolution. For each measure, a second rater scored a random set of about 35 protocols to establish reliability.

- *Summary:* A 5-point scale was developed to rate the summaries collected at posttest. Responses restating naive conceptions were rated 1, responses showing the recall of trivial facts were rated 2, responses showing the incorrect assimilation of new information were rated 3, responses showing some aspects of a Darwinian conception were rated 4, and responses showing a Darwinian conception were rated 5. The interrater reliability of this measure was .93 (Pearson correlation), with 82% agreement.
- *New questions:* A 5-point scale was developed to rate the posttest wonderment question. Off-task comments and nonresponses were rated 1, questions on information unrelated to the text were rated 2, questions on text-related information were rated 3, questions indicating the recognition of a discrepancy between personal knowledge and text information were rated 4, and questions that involved elaboration of a problem or attempts to resolve the discrepancy were rated 5. The interrater reliability of this measure was .94 (Pearson correlation), with 84% agreement.
- *Application questions:* A 5-point scale was developed to rate the near- and far-application questions. Irrelevant responses were rated 1, responses showing

naive conceptions were rated 2, responses showing the incorrect assimilation of new information were rated 3, responses indicating a new idea without elaboration were rated 4, and responses showing the correct application of the principle of natural selection were rated 5. The interrater reliabilities were .86 (Pearson correlation), with 83% agreement, and .95 (Pearson correlation), with 90% agreement, for the near- and far-application questions, respectively.

Belief change. Students rated the eight specific statements at pretest and posttest and the four factor statements at pretest, posttest, and on each occasion when they were presented with a probe statement. These 10 student ratings provided a continuous profile of belief change. As with the pretest measures, correlations between students' ratings and the criterion measures were computed.

RESULTS

Developmental Differences in Knowledge-Processing Activity

Differences in Mean Knowledge-Processing Activity

Ratings were pooled across the seven statements to produce an average score, called *knowledge-processing activity,* for each student. A three-way analysis of variance (ANOVA; Grade × Condition × Peer) showed a significant main effect for grade, $F(1, 100) = 5.69, p < .05$, favoring the Grade 12 students. A significant main effect for condition was also obtained and is reported in the next section. No main effects for peer group were obtained, and there were no interaction effects.

Differences in Proportional Use of Specific Activities

Further analyses were conducted to examine the developmental differences for each level on the knowledge-processing activity scale. Due to the small number of instances, Level 1 and Level 5 responses were collapsed with the adjacent levels, resulting in three levels: (a) assimilative activity, (b) surface-constructive activity, and (c) knowledge-building activity (Table 2). A three-way ANOVA (Grade × Condition × Peer) on the assimilative activity showed a significant effect for grade, $F(1, 100) = 4.31, p < .05$, with a higher mean for the Grade 9 students, and a three-way ANOVA on knowledge-building activity showed a marginally significant effect for grade, $F(1, 100) = 3.14, p < .08$, favoring the Grade 12 students. This analysis also shows a developmental shift toward high-level, constructive activity.

TABLE 2
Proportional Use of Different Levels of Knowledge-Processing Activity for Grades and Conditions

	Direct Assimilation		*Surface-Constructive*		*Knowledge Building*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Assimilation						
Individual						
Grade 9	.67	.29	.22	.19	.11	.14
Grade 12	.50	.18	.30	.17	.12	.20
Peer						
Grade 9	.54	.26	.35	.15	.11	.17
Grade 12	.52	.24	.34	.16	.14	.18
Conflict						
Individual						
Grade 9	.44	.29	.30	.22	.25	.27
Grade 12	.37	.20	.30	.20	.33	.30
Peer						
Grade 9	.40	.31	.42	.27	.17	.23
Grade 12	.17	.20	.46	.19	.36	.23

Conflict Versus Assimilation

Conflict and Knowledge-Processing Activity

The three-way ANOVA (Grade × Condition × Peer) on knowledge-processing activity ratings also showed a significant main effect for condition, $F(1, 100) = 21.10$, $p < .01$, favoring the conflict condition. The three-way ANOVAs on the proportional use of the three different levels of knowledge-processing activity showed significant condition effects for assimilative activity, $F(1, 100) = 22.90$, $p < .01$, with a higher mean for the assimilation group, and for knowledge-building activity, $F(1, 100) = 13.90$, $p < .01$, favoring the conflict group. Both analyses indicate therefore that the level of constructive activity was higher in the conflict group. As reported earlier, peer condition and interactions were not significant.

Conflict and Knowledge Quality

Table 3 shows the mean scores of posttest learning for grades and experimental conditions. In order to increase reliability and to provide a summary presentation of results, the four posttest qualitative measures were combined to produce a single composite score called *knowledge quality*. The combination was based on the

TABLE 3
Posttest Knowledge Quality Scores for Grades and Conditions

	Assimilation				*Conflict*			
	Individual		*Peer*		*Individual*		*Peer*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Summary								
Grade 9	2.77	1.06	2.71	0.91	3.13	1.25	2.50	1.09
Grade 12	2.60	1.06	2.93	1.07	3.23	1.17	4.08	0.67
Wonderment								
Grade 9	1.85	0.80	1.79	0.70	2.07	1.28	2.07	1.38
Grade 12	2.13	1.25	1.57	1.28	2.82	1.04	2.25	1.42
Near application								
Grade 9	3.38	1.50	1.79	0.70	2.80	1.32	2.67	0.89
Grade 12	2.20	0.56	2.93	1.59	3.31	1.38	3.58	1.58
Far application								
Grade 9	2.08	0.95	1.86	0.86	2.40	0.99	2.25	0.75
Grade 12	1.93	0.59	2.14	1.10	2.77	1.30	2.67	1.30

loading of each measure on the first component of a principal components analysis. The first component accounted for 55% of the variance, and the loadings were as follows: .80 for summary, .80 for new questions, .71 for near-application, and .75 for far-application.

A three-way ANOVA (Grade × Condition × Peer) on the knowledge quality score showed a significant condition effect, $F(1, 100) = 7.78$, $p < .01$, favoring the conflict group, and an interaction effect of Condition × Grade, $F(1, 100) = 4.19$, $p < .05$. An examination of the means indicated that the effect of conflict on knowledge quality was limited to Grade 12 and was absent at Grade 9 (see Table 3).

Corresponding analyses of the individual measures were conducted using a multivariate ANOVA, and the following results were found: Significant condition effects were obtained for summary, $F(1, 100) = 5.72$, $p < .05$, and for far-application, $F(1, 100) = 7.21$, $p < .01$. A marginal effect was obtained for new questions, $F(1, 100) = 3.46$, $p < .06$. All of the preceding favor the conflict condition. Interaction effects of Condition × Grade were also obtained for summary, $F(1, 100) = 4.09$, $p < .05$, and for near-application, $F(1, 100) = 6.01$, $p < .05$, favoring the older students in the conflict condition.

Conflict and Belief Change

A three-way analysis of covariance (ANCOVA; Grade × Condition × Peer) was conducted on the posttest specific-statement ratings, controlling for the pretest ratings. A significant condition effect was obtained, $F(1, 100) = 5.14$, $p < .05$, favoring the conflict group. A three-way ANCOVA on factor-statement ratings also showed a significant main effect for condition, $F(1, 100) = 16.50$, $p < .01$.

Ordering Effects of Individual Statements

First probe statement. The preceding analyses examined the role of conflict based on the overall effects of the entire set of probe statements. Further analyses were conducted to examine the effects of the ordering of statements. Figure 2 shows the profiles of belief change for the assimilation and conflict conditions. Ten observation points are included: (a) pretest ratings of factor statements, (b) ratings of factor statements at each successive presentation of the eight probe statements, and (c) posttest ratings of factor statements. A trend analysis on these data showed a quadratic component of Condition × Occasion, $F(1, 106) = 58.60$, $p < .001$, indicating that the profiles of change for the assimilation condition and the conflict

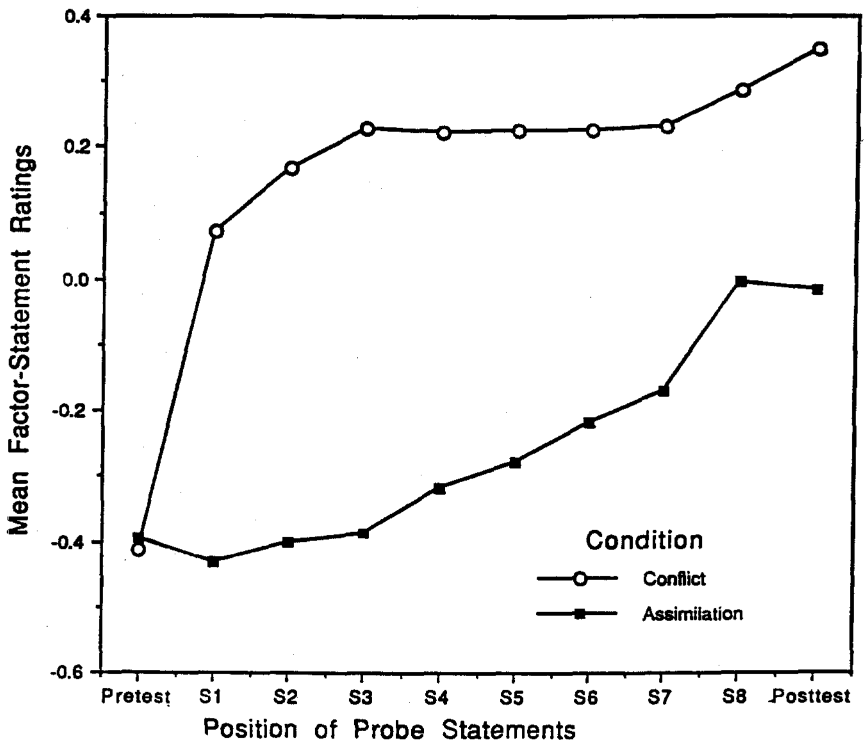


FIGURE 2 Profile of belief changes with successive presentations of probe statements.

TABLE 4
Percentage of Knowledge-Processing Activity in Each Category for the First Probe Statement

Knowledge-Processing Activity	*Conflict Condition*	*Assimilation Condition*
1 Subassimilation	0.0	3.6
2 Direct assimilation		
Stonewalling	7.7	5.4
Patching	3.8	7.1
Distortion	17.3	62.5
3 Surface-constructive		
Paraphrase	15.4	8.9
Exception	5.8	1.8
Juxtaposition	0.0	5.4
4 Implicit knowledge building		
Problem recognition	17.3	1.8
Explanation-driven inquiry	19.2	1.8
5 Explicit knowledge building	13.5	1.8

condition were significantly different. Inspection of the profiles in Figure 2 shows that the quadratic interaction is due to students in the conflict condition having a decreasing rate of change—changing rapidly early on, and then leveling out—and those in the assimilation condition having a steady or increasing rate of change.

Figure 2 also shows a huge difference between conditions for the first probe statement. According to the way the probe statements were ordered, the first probe statement in the conflict condition indicates the greatest degree of discrepancy between student beliefs and new information, whereas the first probe statement in the assimilation condition indicates the least. Not only were there large differences between conditions for belief-change ratings on the first probe statement, but the distribution of knowledge-processing activities on this statement also differed substantially (see Table 4). Of all the responses to the first probe statements, 50% were classified as knowledge building in the conflict condition. In contrast, 79% were classified as low-level responses in the assimilation condition. These findings show that maximal conflict triggered more high-level, knowledge-building activity.

Ordering effects of same probe statement. Analyses were also conducted to examine student responses to the same probe statement in different positions. The two statements that were maximally compatible and incompatible were selected for analysis. Because the order of probe statements was individualized, these two statements could be identified as the ones that occurred most frequently as the first probe statement for the conflict condition and the assimilation condition, respectively. CPE was the name of the probe statement that contradicted both the purpose and environmental conceptions and was the most incompatible with student beliefs. AP was the name of the probe statement that was most congruent with students' beliefs (see the Appendix).

It was hypothesized that the effect of the same incompatible statement on knowledge-building activity and belief-change ratings would be greater in early presentation, when conflict was maximized, than in late presentation, when conflict was relatively smaller. On the other hand, the effect of a more compatible statement would be smaller in early presentation, when there was a greater tendency to assimilate. In order to include as many instances as possible, Positions 1, 2, and 3 were categorized as early presentation, and Positions 6, 7, and 8 were categorized as late presentation.

Table 5 shows the proportions of different levels of knowledge-processing activity for CPE with early presentations (P1–P3), when conflict was maximized, versus late presentations (P6–P8), when conflict was smaller. The frequency distribution shows that 39% of all instances of early presentation were accompanied by knowledge-building activity (Levels 4 and 5) compared with only 9% for late presentation. There was a high proportion of low-level, assimilative responses for the compatible statement AP at both positions. The occurrence of high versus low responses across different positions was about the same (see Table 5).

An ANOVA on mean knowledge-processing activity ratings was then conducted to examine the position effects of the probe statements. A significant position effect was obtained for CPE, $F(1, 100) = 15.02$, $p < .01$, favoring early presentation; there were no differences for AP. Similarly, an ANOVA on belief-change ratings showed a significant position effect for CPE, $F(1, 100) = 16.92$, $p < .01$, favoring early presentation. Differences for the compatible statement were not significant. Even the exact same probe statement, when the discrepancy was greater, produced more knowledge-building activity and belief change.

These findings, taken together, indicate that conflict led to more frequent use of knowledge-building activity, higher scores in quality of posttest knowledge, and greater belief change.

TABLE 5
Percentage of Knowledge-Processing Activity for Incompatible (CPE) Versus Compatible (AP) Statements and for Early Versus Late Presentations

	Incompatible (CPE)		*Compatible (AP)*	
Knowledge-Processing Activity	*Early (1–3)*	*Late (6–8)*	*Early (1–3)*	*Late (6–8)*
Subassimilation	2.0	10.1	1.7	0.0
Direct assimilation	22.4	40.4	68.3	70.0
Surface-constructive	36.7	40.4	21.7	20.0
Implicit knowledge building	30.6	9.1	8.3	3.3
Explicit knowledge building	8.2	0.0	0.0	6.7

Individual Versus Peer Interaction

Peer Interaction and Knowledge-Processing Activity

As reported previously, the three-way ANOVA (Grade × Condition × Peer) on knowledge-processing activity showed no main effect for peer interaction. However, the proportional use of the three levels of knowledge-processing activity showed significant main effects for assimilative activity, $F(1, 100) = 4.76$, $p < .05$, with a higher mean in the individual condition and for surface-constructive activity, $F(1, 100) = 8.58$, $p < .01$, favoring the peer-interaction condition. This indicates that the peer condition may have reduced the amount of low-level, constructive activity and increased the amount of middle-level activity.

Peer Interaction and Knowledge Quality

A three-way ANOVA (Grade × Condition × Peer) showed no significant peer effects on composite posttest knowledge-quality scores. Corresponding analyses on the individual posttest measures showed a significant Peer × Grade effect for summary, $F(1, 100) = 5.34$, $p < .05$, and a near-significant Peer × Grade effect for near-application, $F(1, 100) = 2.98$, $p = .08$, favoring Grade 12 students in the peer condition.

Peer Interaction and Belief Change

There were no significant effects for peer interaction in the ANCOVA of the specific-statement ratings. Factor-statement rating was the only score that was identical for both students in the dyads; they had to come to a consensus about the ratings. A three-way ANCOVA (Grade × Condition × Peer) on the factor-statement ratings showed no main effects for peer interaction. However, a significant Peer × Condition interaction effect, $F(1, 100) = 4.25$, $p < .05$, was obtained, favoring the conflict grouping in the peer condition.

Age, Prior Knowledge, Conflict, Knowledge-Processing Activity, and Conceptual Change

Multiple Regression

To look at the effect of knowledge-processing activity on conceptual change, and specifically to test whether knowledge-processing activity predicted posttest knowledge quality over and above prior knowledge and condition effects, a multiple regression analysis was conducted, with grade entered first, followed in order by prior knowledge, condition, and knowledge-processing activity.

TABLE 6
Multiple Regression of Grade, Prior Knowledge, Conflict, Knowledge-Processing Activity, and Posttest Knowledge Quality

	R	R^2	R^2 *Change*
Grade	.127	.016	.016
Prior knowledge	.363	.132	.116*
Condition (conflict)	.437	.191	.060*
Knowledge-processing activity	.695	.483	.292*

*$p < .01$.

The measure of prior knowledge was a composite, obtained from the three available measures of prior knowledge: (a) knowledge activation, (b) pretest specific-statement scores, and (c) pretest factor-statement scores. The three measures were combined according to their loadings on the first component of a principal components analysis. The first principal component of the analysis accounted for 57% of the variance with the following loadings: .84 for knowledge activation, .77 for specific-statement score, and .64 for factor-statement score. A three-way ANOVA (Grade × Condition × Peer) showed that prior knowledge did not differ significantly between conditions.

Table 6 shows that grade did not contribute to posttest knowledge quality. When prior knowledge was added, it explained 13% of the variance. When conflict was added, it explained an additional 6% of the variance. Finally, when knowledge-processing activity was added, it explained an additional 29% of the variance. Thus, knowledge-processing activity was a significant contributor to posttest knowledge quality over and above grade, prior knowledge, and conflict.

Path Analysis

A path analysis was conducted to obtain a more coherent picture of the possible causal relations among grade, prior knowledge, conflict, knowledge-processing activity, and conceptual change. Table 7 shows the correlations among the different variables. Path analysis requires prior assumptions about causal ordering. The assumptions in this analysis are as follows: Because grade and condition were preselected, they could only affect the other variables and not be affected by them. Because knowledge activation was obtained prior to the knowledge-processing task, prior knowledge could affect knowledge-processing activity, belief change, and knowledge quality. Furthermore, knowledge-processing activity could affect both posttest belief change and knowledge quality but not vice versa.

Path coefficients based on standardized regression weights are shown in Figure 3. The causal paths show that grade, prior knowledge, and conflict affected knowledge-processing activity (.24, .31, and .38, respectively, $p < .01$). Knowl-

TABLE 7
Correlations of Grade, Condition, Prior Knowledge, Knowledge-Processing Activity, and Posttest Learning

	Condition (Conflict)	*Prior Knowledge*	*Knowledge-Processing Activity*	*Knowledge Quality*	*Factor Statements (Gain Score)*	*Specific Statements (Gain Score)*
Grade	.03	–.09	.19*	.13	.00	.06
Condition (conflict)		.05	.39**	.26**	.35**	.17
Prior knowledge			.31**	.33**	–.22	–.34*
Knowledge-processing activity				.68**	.47**	.38**
Knowledge quality					.40**	.44**
Factor statements (gain score)						.63**

*$p < .05$. **$p < .01$.

edge-processing activity in turn exerted an effect on the gain in specific-statement scores (.57, $p < .01$) and on knowledge quality (.64, $p < .01$). The negative path weight from prior knowledge to specific-statement gain score suggests that high-knowledge students obtained less gains, but because the gain score is calculated as posttest knowledge minus pretest knowledge, this result is probably an artifact. For the measures that did not involve gain scores, the direct path from prior knowledge to posttest knowledge quality was small but positive. Additionally, the direct paths from grade and conflict to specific-statement gain score and knowledge quality are all small and insignificant.

These results indicate that the effects of grade, prior knowledge, and conflict on knowledge quality and belief change are largely mediated by the increase in knowledge-processing activity that accompanies increases in these variables. Path analyses using the measure of factor-statement score indicated very similar results. Grade, prior knowledge, and conflict did not lead to conceptual change except when they were mediated by knowledge-processing activity.

DISCUSSION

This study examined high school students' processing of contradictory information in the domain of biological evolution. From an analysis of protocols, five different levels were identified: At the assimilation levels (Levels 1 and 2), new information was ignored, rejected, and distorted to make it fit with existing beliefs. At the surface-constructive level (Level 3), new information was comprehended, although its implications for one's beliefs were not considered. At the knowledge-building level (Levels 4 and 5), new information was considered something problematic and in need of explanation. The results suggest that the conceptual framework provided by the knowledge-processing activity scale was useful: A path analysis showed that knowledge-processing activity, as defined by the scale, exerted a direct effect on conceptual change and mediated the effects of conflict.

How Students Learn From Incompatible Information

Although the knowledge-building scale was derived initially from an intuitive understanding, emerging from the findings are several features that characterize what may be involved in knowledge construction in complex domains.

Surface Versus Deep Features

A distinction could be made between an emphasis on surface versus deep features of the problem. At the most shallow level, students reacted to isolated words (Level 1) or responded to the salient surface features of the text statements

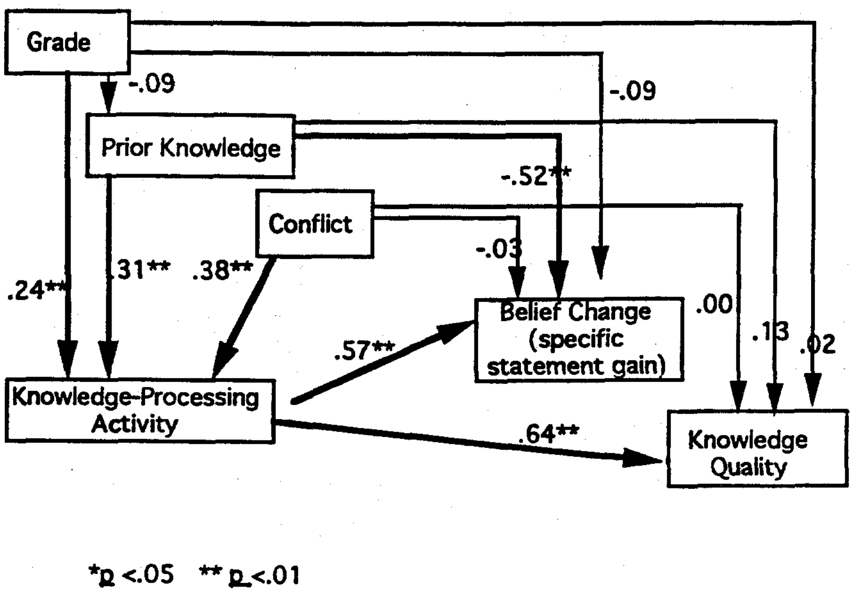


FIGURE 3 Path analysis of the contribution of grade, prior knowledge, conflict, and knowledge-processing activity to conceptual change.

(Level 2). Other responses (Level 3) suggested that students were concerned with constructing a text model by paraphrasing the new information. Although these responses indicated attempts to understand what the text information said, they were not related to the revision of situation models (Mannes & Kintsch, 1987). Knowledge-building responses, however, suggested students' concerns with a deeper problem: the principle of evolution represented in the text and how it fits with their prior beliefs. For example, one student said, "I thought evolution is a competitive thing; maybe it could take place without wiping out the other animals." Similarly, another student seemed concerned with the principle of mechanism: "But how did the animals change? So, they change because of their environment, but how did they change?"

These findings are consistent with the well-established idea that experts represent problems at a deep level, whereas novices attend only to the surface features (Chi, Feltovich, & Glaser, 1981). Although this is often suggested to be the result of the high knowledge level of experts in their domain, the more expert of the low-knowledge learners in this study also seemed more capable of avoiding reliance on surface features. Even though they had very inadequate knowledge of the domain, they were trying to move in the direction of formulating problems at a deeper level. This process may facilitate the acquisition of domain expertise and may define a sort of learning expertise apart from domain knowledge (Bereiter & Scardamalia, 1993).

Piecemeal Editing Versus Delayed Interpretation

Although working to identify deep principles may be important, it may be difficult to know what kind of information to attend to when one does not know very much about a domain. Delayed interpretation and accumulation of new information may be relevant.

In the experiment, eight probe statements were presented one at a time to examine students' approaches to new information. Assimilation responses often involve piecemeal editing or some kind of sweeping changes, as if each statement had no bearing on the previous ones. Conversely, students employing knowledge-building responses recognized the complexity of the situation and that they needed to invoke problem-solving processes, including accumulating more information, seeking connections among contradictory pieces of information, and evaluating a new statement in the context of other evidence and hypotheses. In one student's own words, "Let's keep them in consideration." Or as another student said, "They seem to contradict each other—I need to make a connection," which may be important for setting up pointers to difficult concepts in revising their understanding.

These results parallel findings regarding the distinction between convergent students who seek coherent understanding versus oscillating students who move from one set of ideas to another (Lewis, 1991). Indeed, focusing on the multiplicity of relations among pieces of information (Brown & Day, 1983) and emphasizing coherence (Scardamalia & Bereiter, 1984) are crucial to meaning construction.

Theory-Evidence Conflation Versus Problem Recognition

Although the contradictory statements were designed to confront students' beliefs, students were often not mystified by what they did not know. Many conflated new information with their prior beliefs ("This is what I thought") and indicated their agreement with the new information that contradicted their beliefs. Conversely, knowledge-building responses reflected an active stance in identifying conflict and attempts to reconcile the discrepancies. Students employing a knowledge-building approach do not avoid conflict but use the contradictory statements as opportunities for upgrading their domain understanding.

Research on incompatible text information has shown that students let their prior knowledge override text interpretation (Alvermann, Smith, & Readence, 1985; Lipson, 1982; Maria & MacGinitie, 1982). In this study, students who directly assimilated new information did not discriminate new information from their beliefs. The more expert learners, however, recognized that something was different; hence, they were able to subject their knowledge to inquiry. Just as theory-evidence coordination is important in scientific experimentation (Klahr & Dunbar, 1988; Kuhn, 1989), a problem-solving process is required for identifying and resolving the discrepancy between new information and domain understanding.

Patching Versus Explanation-Based Inquiry

Further to the recognition of knowledge conflict, some students continued to engage in explanation-based inquiry to resolve the problems. The importance of explanation in science learning has been well documented (Bielaczyc et al., 1995; Chi, de Leeuw, et al., 1994). In learning about difficult concepts, students may generate inaccurate explanations due to incompatible prior knowledge. Nevertheless, students employing a knowledge-building approach may benefit more compared with those who provide a one-shot explanation to eliminate discrepant facts that do not fit their beliefs. In viewing new information as problematic and as requiring explanations, students are engaged in an ongoing process of problem recognition and conflict resolution. Even if they have constructed inaccurate explanations, they are more likely to detect anomalies in upcoming information and to revise their models continually.

These general themes suggest that learning from novel, incompatible information involves an approach that views learning as problematic. In contrast to using a problem-minimization approach, the more expert learners attend to deep principles, construct coherence from discordant information, seek out knowledge conflict, and engage in explanation-based inquiry. Beyond constructing a text model, these students engage in revising, extending, and reconstructing their situational models (Kintsch, 1989). Consistent with earlier results on constructive activity in learning from text (Chan et al., 1992), a problem-centered approach to learning plays a crucial role in knowledge construction even when students have limited prior knowledge.

Although our analysis suggests that problem-centered, knowledge-building activity fosters conceptual change, it is important to consider alternative explanations. One possible argument is that the contrasting approaches of knowledge building and direct assimilation may differ primarily with respect to the subject's acceptance or rejection of the probe statement. Our analysis, however, shows that responses coded as direct assimilation and distortion as well as direct assimilation and patching involve students' acceptance of the probe statements even though they did not comprehend the text ideas (see earlier protocol examples). It is not uncommon to find students who explicitly state that they agree with the probe statement (e.g., "Yes, I agree with this ... ") and then twist the new information (distortion) or make small changes (patching) to minimize the differences between their beliefs and the new information.

Of the different kinds of assimilation response, stonewalling, which constituted a relatively small percentage of the direct assimilation responses (see Table 4), was the only kind that indicated a student's rejection of the probe statement. Stonewalling was categorized as direct assimilation because it suggests students' tendency to let their prior knowledge override consideration of any new information that does not fit. More important, this kind of response is different from scientists' rejection of alternative theories. Stonewalling refers to a minimization of effort, by excluding new information in a domain about which the student knows little. As shown in the protocol excerpt given earlier, in connection with the scale description, there were no attempts to understand the actual examples (evidence) presented in the probe statement. On the other hand, scientists attend to discrepant evidence and reject rival positions by generating alternative explanations to account for the differences.

Although it is less apparent whether responses in the transitional level indicate belief in the probe statements, it would seem that paraphrasing does involve a student's acceptance of the new information. In addition, juxtaposition and exception both suggest that the student believes (at least partially) in the truth of the statement, but that its truth has no bearing on his or her beliefs (e.g., "I guess this is true, but this is the exceptional case"). Despite a higher frequency of middle-level responses among students in the peer condition, they did not perform better than students in the individual condition in posttest learning. Some evidence suggests that paraphrasing does not improve conceptual-change learning (Chi, de Leeuw, et al., 1994). Although the role of paraphrasing in learning from scientific information remains to be examined, these findings suggest that mere belief in the probe statements could not account for differences in posttest performance.

The idea of students' acceptance or rejection of new information is interesting because it helps to shed light on what knowledge-building activity may entail. Drawing on philosophical arguments and psychological evidence, Gilbert (1991) discussed how mental systems believed and argued that the acceptance of an idea is part of the comprehension process. In other words, to comprehend a proposition, a person has to accept that proposition implicitly; only later might that person decide whether the idea needs to be rejected. Gilbert's postulation is supported by other theorists, who claim that if one is to understand a proposition, one must assume its truth conditions (Dowty, Wall, & Peters, as cited in Gilbert, 1991), "imagine how the world should be granted its truth" (Johnson-Laird, as cited in Gilbert, 1991), or create a temporary context assuming the truth of the proposition (Rips & Marcus, as cited in Gilbert, 1991).

Consistent with this position, students' beliefs in the probe statements may be necessary for comprehending the novel information. It is perhaps not surprising that knowledge-building responses tend to reflect students' acceptance of the probe statements as they seek to understand the new information in an unfamiliar domain. Note that students' acceptance of a statement does not guarantee their success in comprehension. In fact, a majority of students asserted their acceptance of the probe statements but then conflated the new information with their existing beliefs. Mere acceptance of the probe statement cannot account for success in conceptual change. Students employing knowledge-building activity were able to avoid premature assimilation of new information, to bracket their beliefs, and to create a temporary context to make sense of the new information.

Knowledge Building as a Mediator of Conflict in Conceptual Change

Unlike most studies that have investigated the effect of conflict by comparing group differences, this study utilized an online think-aloud methodology to track individual differences in students' responses to conflict. Consistent with the general view that conflict promotes cognitive change, these results show that, when conflict was maximized, students performed better. However, when knowledge-processing activity was added to the analyses, the results show that the effects of conflict on conceptual change increased only when there was an increase in knowledge-building activity.

Discrepant findings about the effects of contradiction have been explained on the basis of what is done externally to alter the learning settings; for example, augmented activation is better than nonaugmented activation (Alvermann & Hague, 1989; Guzzetti & Glass, 1993). Alternatively, although students' conceptual-processing tactics for anomalous information have been well documented, emphasis has been given to coping strategies rather than to deep-processing activity (Chinn & Brewer, 1993).

Consistent with findings on self-regulated science learning (Anderson & Roth, 1989), these results provide a convergent source of data showing the importance of both *conflict* and *constructive activity*. In addition, this study begins to elucidate the relations between them. The path analysis suggests that conflict may trigger knowledge-building activity, which then leads to conceptual change, but that conflict in the absence of knowledge building will not produce conceptual change. A distinction needs to be made between external and internal conflict: Often, contradictory information is presented in the hope that it will produce cognitive conflict. These results seem to show that, without knowledge-building activity, confrontation may not produce cognitive conflict but only assimilation or external competition.

Accordingly, this study provides an explanatory hypothesis for the equivocal findings in the cognitive-conflict paradigm. For example, contradiction effects were obtained with some groups of students but not with others in parallel studies (Alvermann & Hynd, 1989; Champagne et al., 1985; Guzzetti & Glass, 1993). Although independent measures of knowledge-processing activity would be required to test the hypothesis, it is plausible that students might be engaged in different levels of knowledge building. The findings of this research at least indicate the desirability of obtaining measures of knowledge-processing activity in comparative studies of conceptual change.

Although the path-analysis findings provide a clear picture of the mediating effect of knowledge-building activity in conceptual change, it is important to recognize that this picture would likely be considerably complicated by the inclusion of the large number of individual difference variables that might be involved. Among candidate variables are students' epistemic attitudes (Qian & Alvermann, 1995; Schommer, 1993) and such traditional explanatory variables as IQ and motivation. Such individual difference variables may be assumed to have reciprocal rather than unidirectional causal effects: IQ, for instance, might influence knowledge-building activity but might in turn be influenced by it. These other variables do not so much represent counterexplanations as alternative routes toward explanation. The route taken in this study has the advantage in educational terms of accounting for conceptual change on the basis of variables that are potentially modifiable by instruction, but it remains an open question whether this route will lead to better explanations as judged by broader theoretical or empirical criteria.

Collaborative Processing of Contradictory Information

This study also examined whether peer collaboration fostered knowledge-building activity and conceptual change when students were confronted with contradictory information. Despite the lack of main effects, some interaction effects were obtained showing that the older students performed better in the peer condition, whereas the younger students performed better in the individual condition. In addition, students in the conflict condition benefited more from peer collaboration than did those in the assimilation condition.

Analysis of scientific discourse is now a research theme of emerging interest (e.g., Pea, 1993; Roschelle, 1992). Putting students in groups is not enough; there is a need to "unpack" what is going on in group interaction processes. Our findings are consistent with the idea that the effects of peer collaboration may vary depending on the group processes. Older students and those facing maximal conflict were more likely to employ more sophisticated discourse processes, which may have led to the differential results.

The overall quantitative findings show that not all students benefited from peer collaboration. More detailed analysis has been conducted to examine what successful and unsuccessful students do differently to construct their joint understanding (for details, see Chan, 1995). The following two excerpts from different dyads provide examples illustrating debilitating versus productive discourse moves:

Dyad 1

1 S1A: Maybe there is something to do with genes with the long legs, so a deer cannot choose to have long legs. However, they may be born with longer legs. So, that may be chance. So, [name of student], does it have something to do with chance? Is it possible that this card has a double meaning?

2 S1B: Probably. The deer that are born with longer legs have a better chance of survival. It does have something to do with chance.

3 S1A: But chance [Card 4] is pretty high up already. Would you want to change it?

4 S1B: I think it is good.

5 S1A: I think it is fine. Is there a right or wrong answer to it?

6 S1B: Did we get any right?

In this example, S1A initiated a deepening move, generated a problem, and requested information from his peer (line 1). Although his statement consisted of new information that was different from what S1B believed, the difference was not recognized. Instead of treating this new piece of information as problematic and attempting to explain what was said, S1B responded by giving a simple text paraphrase (line 2). Directly assimilating the new information, S1B equated what S1A said about chance with his everyday understanding (line 2, "[Some deer] have a better chance of survival"). Interestingly, S1B's utterance, which should have caused some problem or conflict for S1A, was simply ignored. S1A responded with a superficial move, treating S1B's response as satisfactory (line 3). Inquiry was terminated, and the problem was apparently settled. The last few moves (lines 4–6) suggest that the two students were concerned with a task-completion activity: getting the correct ratings.

Dyad 2

1 S2A: I'm not sure if it's a moth, but they noticed something that became pitch black.

2 S2B: It became pitch black because of what?

3 S2A: It developed a darker color because the pollution affected the moth. I guess the cells go through a color change. So this should be higher [Card 3—environment card].

4 S2B: But this [text] is saying, basically, it is not dependent on the environment.

5 S2A: No. Yeah. Wait. [Rereads text.] See, if this is true, I find that difficult to agree with this [text] because if there is some environmental change, it will kill the species. I don't know.

In response to the probe statement, S2A recalled her prior knowledge (line 1). S2B initiated a problem-centered move by asking S2A to explain the data (line 2, "because of what?"). S2A explained and constructed her argument in favor of environmental change (line 3). S2B identified a problem and pointed out the discrepancy between S2A's explanation and the new information (line 4). Unlike Dyad 1, who ignored new information from their peers, Dyad 2 demonstrated a careful uptake of information. Instead of assimilating the new information or providing a justification to defend her claim, S2A responded with another problem-centered move by trying to deal with the conflictual information posed by her peer (line 5). She reread the information (line 5, "No. ... Wait.") and identified the knowledge conflict (line 5, "I find that difficult to agree with this because ... ") even though she did not have enough information to resolve the problem then. In treating their peer's responses as problems to be dealt with, the dyad continued to make progress in their discourse.

Although detailed discourse analysis is beyond the scope of this study, these examples suggest that different kinds of discourse moves might be employed that resemble a direct assimilation versus a knowledge-building approach to learning. Indeed, information from peers needs to be processed and taken up just as information from texts. Although it is useful to have students talk about science, the benefits probably stem from the kind of collaborative constructive activity undertaken in peer learning. These preliminary analyses emphasize the importance of tracking the discourse processes and suggest that the knowledge-building approach may provide a framework for examining scientific discourse. Further investigations are needed to examine whether problem-centered discourse moves are related to success in collaborative learning.

Instructional Implications

Common approaches in classroom instruction emphasize curriculum sequencing that involves easy to difficult, concrete to abstract, or familiar to unfamiliar. Although it is common to present students with familiar information, these findings support the idea of maximizing incongruity. A minicrisis can be used to provide the opportunity for knowledge restructuring. Instructional strategies that aim to produce flabbergasting effects may help students to reconsider their beliefs. An implementation of the probe-statement procedure in a classroom setting might involve teachers presenting stunning statements or scenarios rather than sequenced information. Problems with conventional textbook approaches indicate that a sequenced approach often does little to promote conceptual change. Stunning statements and discrepant facts may trigger students to recognize difficulties and construct alternative explanations to account for the discrepancies.

Although presentation of conflictual information is important, the main finding of this study suggested that conflict needs to be accompanied by students' use of knowledge-building activity. Although the importance of conflict in conceptual change has been recognized, the distinctive idea here is encouraging students to be active agents in their own conceptual change.

In instructional practice that involves conceptual-change teaching, teachers often take on considerable responsibility for students' learning—activating prior knowledge, providing the scientific conceptions, and evaluating outcomes of conflict resolution. A knowledge-building approach to conceptual change, however, emphasizes the importance of students' problem-centered inquiry. The present knowledge-building scheme—consisting of a continuum of coping and knowledge-building activity—may provide a basis for developing teachable strategies for fostering active learning. For example, helping students to identify coping tactics may help them avoid assimilation as they gradually move toward adopting more sophisticated knowledge-building strategies. Instructional experimentation would also help to assess the degree to which knowledge-building activity could be fostered.

CONCLUSIONS

This study integrated the two research strands of cognitive conflict and constructive processes to investigate the problem of learning from incompatible information. Tracking individual differences in how students responded to contradictory information, this study provided a theoretical framework based on the idea of knowledge building to account for the discrepant experimental findings in conceptual change. Conflict in itself is not enough; it needs to be mediated by students' knowledge-building activity. Viewing learning as problematic minimizes assimilation and leads to more conceptual change. The findings may also shed light on the problem of constructing knowledge in unfamiliar domains and highlight the importance of constructive activity in learning.

ACKNOWLEDGMENTS

This project was partially funded by the Social Sciences and Humanities Research Council of Canada and by the Block Transfer Grant from the Ontario Ministry of Education to the Ontario Institute for Studies in Education. We thank Marlene Scardamalia and other members of the Knowledge Building Research Project for their constructive comments. We particularly express our gratitude to Flemming Kress at William Lyon McKenzie Collegiate for welcoming us to the school and to the many teachers and students who participated in the project.

REFERENCES

Alvermann, D. E., & Hague, S. A. (1989). Comprehension of counterintuitive science text: Effects of prior knowledge and text structure. *Journal of Educational Research, 82,* 197–202.

Alvermann, D. E., & Hynd, C. R. (1989). Effects of prior knowledge activation modes and text structure on nonscience majors' comprehension of physics. *Journal of Reading Research, 83,* 97–102.

Alvermann, D. E., Smith, L. C., & Readence, J. E. (1985). Prior knowledge activation and comprehension of compatible and incompatible text. *Reading Research Quarterly, 20,* 420–436.

Amigues, R. (1988). Peer interaction in solving physics problems: Sociocognitive confrontation and metacognitive aspects. *Journal of Experimental Child Psychology, 45,* 141–158.

Anderson, C. W., & Roth, K. J. (1989). Teaching for meaningful and self-regulated learning of science. In J. Brophy (Ed.), *Advances in research on teaching* (pp. 265–309). Greenwich, CT: JAI.

Bereiter, C., & Bird, M. (1985). Use of thinking aloud in identification and teaching of reading comprehension strategies. *Cognition and Instruction, 2,* 131–156.

Bereiter, C., & Scardamalia, M. (1989). Intentional learning as a goal of instruction. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 361–392). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Bereiter, C., & Scardamalia, M. (1992). Cognition and curriculum. In P. W. Jackson (Ed.), *Handbook of research on curriculum* (pp. 517–542). New York: Macmillan.

Bereiter, C., & Scardamalia, M. (1993). *Surpassing ourselves: An enquiry into the nature and implications of expertise.* La Salle, IL: Open Court.

Bielaczyc, K., Pirolli, P. L., & Brown, A. L. (1995). Training in self-explanation and self-regulation strategies: Investigating the effects of knowledge acquisition activities on problem solving. *Cognition and Instruction, 13,* 221–252.

Biggs, J. (1984). Learning strategies, student motivation patterns, and subjectively perceived success. In J. R. Kirby (Ed.), *Cognitive strategies and educational performance* (pp. 111–134). Orlando, FL: Academic.

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27,* 415–427.

Brown, A. L. (1980). Metacognitive development and reading. In R. J. Spiro, B. C. Bruce, & W. F. Brewer (Eds.), *Theoretical issues in reading comprehension* (pp. 453–481). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Brown, A. L., & Day, J. D. (1983). Macrorules for summarizing texts: The development of expertise. *Journal of Verbal Learning and Verbal Behavior, 22,* 1–14.

Brown, A. L., & Palincsar, A. S. (1989). Guided, cooperative learning and individual knowledge acquisition. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 393–451). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Brumby, M. (1984). Misconceptions about the concept of natural selection by medical biology students. *Science Education, 68,* 493–503.

Champagne, A. N., Gunstone, R. F., & Klopfer, L. E. (1985). Effecting changes in cognitive structures among physics students. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structures and conceptual change* (pp. 163–187). Orlando, FL: Academic.

Chan, C. K. K. (1995). Collaborative processing of incompatible information. In J. D. Moore & J. F. Lehman (Eds.), *Proceedings of the 17th Annual Conference of the Cognitive Science Society* (pp. 340–345). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Chan, C. K. K., Burtis, P. J., Scardamalia, M., & Bereiter, C. (1992). Constructive activity in learning from text. *American Educational Research Journal, 29,* 97–118.

Chi, M. T. H., & Ceci, S. J. (1987). Content knowledge: Its representation and restructuring in memory development. In H. W. Reese (Ed.), *Advances in child development and behavior* (Vol. 20, pp. 91–142). New York: Academic.

Chi, M. T. H., de Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanation improves understanding. *Cognitive Science, 18,* 439–477.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121–152.

Chi, M. T. H., Glaser, R., & Farr, M. (Eds.). (1988). *The nature of expertise.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4,* 27–43.

Chinn, C., & Brewer, W. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63,* 1–49.

Deadman, J. A., & Kelly, P. J. (1978). What do secondary school boys understand about evolution and heredity before they are taught these topics? *Journal of Biological Education, 12,* 7–15.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "cognitive conflict" strategy for conceptual change. Some implications, difficulties and problems. *Science Education, 74,* 555–569.

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's ideas in science.* Philadelphia: Open University Press.

Duschl, R. A., & Gitomer, D. H. (1991). Epistemological perspectives on conceptual change: Implications for educational practice. *Journal of Research in Science Teaching, 28,* 839–858.

Eylon, B., & Linn, M. C. (1988). Learning and instruction: An examination of four research perspectives in science education. *Review of Educational Research, 58,* 251–301.

Gilbert, D. T. (1991). How mental systems believe. *American Psychologist, 46,* 107–119.

Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist, 39,* 93–104.

Glaser, R., & Bassok, M. (1989). Learning theory and the study of instruction. *Annual Review of Psychology, 40,* 631–666.

Guzzetti, B. (1990). The effects of text and reader-based instructional manipulations on concept acquisition. *Reading Psychology, 11,* 49–62.

Guzzetti, B. J., & Glass, G. V. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28,* 116–159.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education, 11,* 541–553.

Hynd, C. R., & Alvermann, D. E. (1989). Overcoming misconceptions in science: An on-line study of prior knowledge activation. *Reading Research and Instruction, 28*(4), 12–26.

Kintsch, W. (1989). Learning from text. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 25–46). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12,* 1–48.

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review, 96,* 674–689.

Lewis, E. L. (1991, April). *The development of understanding in elementary thermodynamics.* Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Linn, M., & Songer, N. (1991). Cognitive and conceptual change in adolescence. *American Journal of Education, 99,* 379–417.

Lipson, M. Y. (1982). Learning new information from text: The role of prior knowledge and reading ability. *Journal of Reading Behavior, 14,* 243–261.

Mannes, S. M., & Kintsch, W. (1987). Knowledge organization and text organization. *Cognition and Instruction, 4,* 91–115.

Maria, K., & MacGinitie, W. (1982). Reading comprehension disabilities: Knowledge structures and non-accommodating text processing strategies. *Annals of Dyslexia, 32,* 33–59.

Maria, K., & MacGinitie, W. (1987). Learning from texts that refute the reader's prior knowledge. *Reading Research and Instruction, 26,* 222–238.

Markman, E. M. (1981). Comprehension monitoring. In W. P. Dickson (Ed.), *Children's oral communication skills* (pp. 61–84). New York: Academic.

Ohlsson, S. (1991). *Young adults' understanding of evolutionary explanations: Preliminary observations* (Tech. Rep.). Washington, DC: Department of Education, Office of Research and Educational Improvement.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education, 67,* 489–504.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1,* 117–175.

Pea, R. D. (1993). Learning scientific concepts through material and social activities: Conversational analysis meets conceptual change. *Educational Psychology, 28,* 265–277.

Pfundt, H., & Duit, R. (Eds.). (1994). *Students' alternative frameworks and science education* (4th ed.). Kiel, West Germany: Institute for Science Education.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education, 66,* 211–217.

Qian, G., & Alvermann, D. (1995). Role of epistemological beliefs and learner helplessness in secondary students' learning science concepts from text. *Journal of Educational Psychology, 87,* 282–292.

Resnick, L. B. (Ed.). (1989). *Knowing, learning, and instruction: Essays in honor of Robert Glaser.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Resnick, L. B. (Ed.). (1993). [Monograph issue]. *Cognition and Instruction, 10*(2–3).

Roschelle, J. (1992). Learning by collaborating. Convergent conceptual change. *The Journal of the Learning Sciences, 2,* 235–276.

Rumelhart, D. E., McClelland, J. R., & the PDP Research Group. (1986). *Parallel distributed processing: Explorations in the microstructures of cognition* (Vols. 1–2). Cambridge, MA: MIT Press.

Salomon, G., & Globerson, T. (1987). Skill may not be enough: The role of mindfulness in learning and transfer. *International Journal of Education Research, 11,* 623–638.

Scardamalia, M., & Bereiter, C. (1984). Development of strategies in text processing. In H. Mandl, N. Stein, & T. Trabasso (Eds.), *Learning and comprehension of text* (pp. 379–406). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Scardamalia, M., & Bereiter, C. (1987). *The psychology of written composition.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. *Journal of Experimental Child Psychology, 49,* 31–57.

Schommer, M. (1993). Epistemological development and academic performance among secondary students. *Journal of Educational Psychology, 85,* 406–411.

Wang, T. Y., & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology, 16,* 103–116.

West, L. H. T., & Pines, A. L. (Eds.). (1985). *Cognitive structure and conceptual change.* Orlando, FL: Academic.

APPENDIX

Factor Statements

HP: Evolution is directed by needs and purposes of animal species.
HB: Evolution is a battle of stronger species killing off weaker ones.
HE: Evolution depends on changes which occur in the environment.
HD: Evolution depends on changes which first occur by chance.

Specific Statements

P1: Animals do not change unnecessarily. They only change when needs arise.
P2: Using or not using part of its body causes changes in an animal's genes and this is passed on to its young over many generations.
B1: In order to survive, animals have to kill the animals that compete with them.
B2: Every animal species has natural enemies and eventually one wins and the other loses. This is how evolution works.
E1: Animals evolve only when they face and must adapt to environmental changes.
E2: In order for evolution to take place, some changes must occur in the physical environment of animals.
D1: New characteristics first appear due to accidental changes in the genetic material of an animal.
D2: We cannot know how animals will evolve in the future, because evolution depends on accidental changes that occur in animals.

Probe Statements

CP1: *An animal cannot evolve by adapting to its environment. It is the environment which selects the well-adapted animals.* A deer cannot choose to evolve long legs although long legs are important for survival. Some deer, however, may be born with longer legs which allow them to run faster. These individuals have a better chance of surviving and leave more offspring.

CP2: *Usually, characteristics that an animal gets during its lifetime are not passed on to its young.* Ranchers have been cutting off the tails of sheep for generations. Baby lambs are still born with tails because the genes that are passed on have not changed.

CPE: *New characteristics arise in animals first by chance, not by needs.* Random changes in the genetic materials through mutation or genetic recombination produce new variations, whether animals need them or not.

CE1: *No matter how much the environment has changed, new characteristics might not appear in an animal.* A particular species of moth has become darker as its environment has been soiled by pollution. This is not because pale-colored moths developed a dark color to hide from their predators, but because there were already a few dark moths around, and these survived better and became more numerous.

CE2: *Even though their physical environments have changed a lot, some species of animals have remained more or less the same.* New characteristics originate due to random changes in genetic material, then survive or disappear depending on environmental conditions.

CB1: *Some species of fish and shrimp have evolved in ways that each one helps the other survive.* The goby fish cannot dig, so the shrimp digs an underwater burrow for it and keeps the burrow free of sand. The goby keeps watch for dangers. If alarmed, the goby ducks into the burrow and the shrimp safely follows.

CB2: *Usually, different animal species do not fight against each other directly.* Many animal species avoid direct competition by eating different foods or eating foods at different times of the day. Animals that are better adapted become more numerous than the less well adapted animals.

AP: *Some animals are well adapted to their environment even though they are almost all eaten by their predators.* If wolves do not eat rabbits, the rabbit population might become so large that they would die of starvation anyway.