Pergamon

Learning and Instruction 11 (2001) 357–380

Learning and Instruction

www.elsevier.com/locate/learninstruc

On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal

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Abstract

The constructivist view of learning pays special attention to students' prior knowledge. One of the core statements of this view is the necessity of connecting students' prior knowledge with the new contents to be taught. Based on this idea, research on conceptual change explored students' prior conceptions overall about scientific phenomena, and instructional strategies were developed to promote conceptual change. One of the most common conceptual change instructional strategies implemented in the classroom was to induce cognitive conflict through presenting anomalous data or contradictory information. First, the paper presents a review of the conceptual change theoretical frameworks that support this strategy. Second, a review of the controversial results obtained in the application of the cognitive conflict strategy in the classroom is presented. Third, a discussion of the possible factors that may explain the difficulties to implement this strategy is introduced. Three kinds of problems may explain these difficulties. The first kind of problem is related to the question about how to make the cognitive conflict meaningful for students. Motivational factors, epistemological beliefs, prior knowledge, values and attitudes, learning strategies and cognitive engagement, and reasoning strategies, as well as social factors, seem to be relevant to lead students to a meaningful conflict. The second kind of problem is linked to more general theoretical and methodological aspects that research on conceptual change still has to solve. Finally, a third group of practical problems related to the implementation of the cognitive conflict strategy in real school settings is presented.

Keywords: Conceptual change; Cognitive conflict; Motivation; Learning strategies; Epistemological beliefs

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PII: S0959-4752(00)00037-2

1. Introduction

Although not all the followers of constructivism share the same ideas about how learning is achieved, it could be said that all of them would agree with the idea of viewing the learner as an active builder of his/her knowledge. One of the most obvious implications of this idea is that students are not a *tabula rasa* when they try to learn in school. What is their prior knowledge? What knowledge are they activating when they are exposed to the school contents and activities that should help them to learn? Recently, Alexander (1996) pointed out the very relevant role of students' prior or base knowledge in learning: "Truly, one's knowledge base is a scaffold that supports the construction of all future learning" (p. 89).

Another well-known assumption of the constructivist view of learning is the importance of connecting the new knowledge to be acquired with the existing knowledge that students have, in order to promote meaningful learning. Therefore, teachers should take into account students' prior knowledge to promote learning. Based on these assumptions, the research on *students' alternative frameworks* (Driver & Easley, 1978; Driver & Erickson, 1983), *students' ideas*, *misconceptions*, *preconceptions*, *naive theories* or *alternative conceptions* (see, for example, Driver, 1995, or Pfundt & Duit, 1994, for an extended review of the terminology employed and a summary of the main results in the field) has flourished for more than fifteen years.

Two important questions, "What is the prior knowledge students bring to the classroom and what are their individual characteristics?" and "How can teachers connect this prior knowledge with the new contents to be learned?", are closely related to what has been named as *conceptual change*. If concepts, beliefs, theories or ideas need to be changed or replaced, as has been proposed by most of the models of conceptual change developed up to now, it is clear that one of the starting points for research was—and still is—to know more about what kind of representations, ideas, and beliefs of theories students have and, what it is more interesting for teaching purposes, how teachers can connect this prior or base knowledge to the new contents to be taught.

Some theoretical models were developed to explain conceptual change (i.e. Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985; Carey, 1985; diSessa 1988, 1993; Vosniadou & Brewer, 1987; Vosniadou, 1994; Chi, 1992; Chi & Slotta, 1993; Chi, Slotta, & de Leeuw, 1994; Thagard, 1992; for a theoretical review see Tyson, Venville, Harrison, & Treagust, 1997). Although not of all them were developed to be applied to the context of school learning, many empirical studies were conducted in an attempt to apply these models to the classroom. Three kinds of instructional strategies can summarise many of the instructional efforts made to promote conceptual change: (a) the induction of cognitive conflict through anomalous data; (b) the use of analogies to guide students' change; and (c) cooperative and shared learning to promote collective discussion of ideas. In this paper, we will focus on cognitive conflict.

First, we will present a brief theoretical review, linking some theoretical literature on conceptual change to cognitive conflict as a strategy to promote it. Second, we will review the results of applying cognitive conflict as an instructional strategy.

Third, some factors that could explain why this strategy was not as successful as expected will be reviewed and, finally, some reflections about the links between the theoretical problems that research on conceptual change still has to solve and its implementation through instructional interventions aimed at generating a cognitive conflict.

2. Cognitive conflict and theoretical models of conceptual change

Most of the models proposed to explain conceptual change have emphasised the role of cognitive conflict as a central condition for conceptual change. Describing the processes of equilibration, Piaget (1975) considered cognitive conflict as a step in this process. He distinguished between adapted and unadapted responses to contradictory information. Unadapted responses are those where individuals do not realise the conflict. Adapted responses are classified into three types: *alpha*, *beta* and *gamma*. Alpha answers involve individuals who ignore or do not take into account the conflicting data. Beta answers are characterised by producing partial modifications in the learner's theory, through generalisation and differentiation (generating an "ad hoc" explanation). Finally, gamma answers involve the modification of the central core of the theory.

The pioneer model of Posner et al. (1982) considered the phase of conflict, generated by dissatisfaction with the existing concepts, as a first step to achieve conceptual change. In this phase of dissatisfaction students should realise they need to "reorganise", "restructure" or change to some extent their existing ideas or concepts. A kind of "metacognitive awareness" seems to be a necessary, but not sufficient, condition to achieve conceptual change in both a weak or a radical sense (Carey, 1985; Vosniadou & Brewer, 1987; Vosniadou, 1994). It seems that to change something, an individual needs to realise that he/she has to change something and to be willing to do it.

Thagard (1992) analysed some conceptual revolutions in science and he proposed a theory of conceptual change to explain how they took place. He stated that in many of these scientific revolutions, anomalous data played an important role in the process of conceptual change that each revolution supposed. He distinguished different steps in the process of substitution of one theory by another: ignoring the anomalous data, incorporation of new data into the old theory, sublation, supplantation and, finally, disregarding the old theory that it is changed by the new one.

Chinn and Brewer (1993) and Chan, Burtis, and Bereiter (1997) proposed a classification of individuals' reactions to contradictory information or anomalous data. Chinn and Brewer proposed seven types of responses to anomalous data: ignoring, rejecting, excluding, holding them in abeyance, reinterpreting, peripheral changes and change of theory. Chan et al. described two major approaches to the processing of contradictory information: *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. They elaborated a knowledge-processing activity scale to evaluate individuals' reactions to the processing of contradictory information. It consisted of the following five levels:

- *subassimilation* when new information is reacted to at an associative level;
- *direct assimilation* when new information is assimilated either as if it was already known or excluded if it does not fit with prior beliefs. New information can be ignored, denied, excluded or distorted to make it fit with prior beliefs. Ad hoc rationalisations are also possible;
- *surface-constructive* when new information is comprehended, but its implications for one's beliefs are not considered. There is no integration of naive ideas with the new information. A new idea can be considered an exceptional case that does not involve the review of one's own beliefs or ideas;
- *implicit knowledge building* when new information is treated as something problematic that needs to be explained. Conflict is identified and new information is considered to be something different from one's beliefs. Inconsistencies are identified and explanations are built to reconcile knowledge conflict;
- *explicit knowledge building* when new information is accumulated for constructing coherence in domain understanding. Connections among the new information are sought and conflicting hypotheses are identified to explain the domain in question.

Limón and Carretero (1997) have summarised these theoretical frameworks. Table 1 shows an integrated view of these positions with the addition of the scale of knowledge-processing activity elaborated by Chan et al. (1997).

3. Applying the cognitive conflict strategy to the classroom: is it efficient and useful to achieve conceptual change?

As Chan et al. (1997) pointed out, "a common approach to fostering conceptual change is based on a conceptual conflict strategy". The usual cognitive conflict paradigm involves: (a) identifying students' current state of knowledge, (b) confronting students with contradictory information which is usually presented through texts (i.e. Guzzetti & Glass, 1993) and interviewers, who make explicit the contradiction or only guide the debate with the student or among peers (small groups or the whole classroom) (i.e. Dreyfus, Jungwirth, & Eliovitch, 1990; Weaver, 1998; Tillema & Knol, 1997), or by the teacher and new technologies, and (c) evaluating the degree of change between students' prior ideas or beliefs and a post-test measure after the instructional intervention. Often, conflict is induced by presenting information that clearly—for the experimenter or for the teacher—contradicts children's or students' ideas, beliefs or theories.

The controversial results obtained through the application of this strategy have been pointed out (i.e. Dreyfus et al., 1990; Dykstra, Boyle, & Monarch, 1992; Chan et al., 1997; Limón & Carretero, 1997). As Chan et al. said, "even when students are confronted with contradictory information, they are often unable to achieve meaningful conflict or to become dissatisfied with their prior conceptions" (p. 2). A certain number of studies support this "negative" result of cognitive conflict to promote conceptual change (i.e. Champagne, Gunstone & Klopfer, 1985; Eylon & Linn, 1988;

Table 1
Reactions to anomalous data and degree of conceptual change (adapted from Limón & Carretero, 1997)

Responses to anomalous data		Degree of conceptual change		Relation between the old and the new theory	Degree of information processing	
Piaget (1975)		Chinn and Brewer (1993)		Thagard (1992)	Chan et al. (1997) Knowledge-Processing Activity Scale	
Unadapted responses	Unawareness of contradiction	Ignore[1]	No conceptual change at all	T1 (old theory)	Subassimilation:	New information is reacted to at an associative level
Adapted responses (awareness of contradiction)	Alpha	Ignore Reject Exclude Abeyance	No conceptual change but awareness of contradiction	T1	Direct assimilation:	—*stonewalling*: ignores, excludes and denies new information and retells one's beliefs.
					New information is either assimilated as if it was something already known or excluded if it does not fit with prior beliefs	—*distortion*: twists, distorts and overinterprets new information to make it fit with prior beliefs. —*patching*: notice surface discrepancy and patches differences by ad hoc rationalizations.
					Surface-constructive:	New information is comprehended, but its implications for one's beliefs are not considered
	Beta	Reinterpret data maintaining T1	Weak restructuring	Incorporating (T2—new theory—is just an extension of T1)	Implicit knowledge building:	—*problem recognition*: identifies conflict and new information is seen as something different to one's beliefs.
				Sublating (T1&T2)	New information is treated as something problematic that needs explaining	—*explanation-driven inquiry*: identifies inconsistencies and constructs new explanations to reconcile knowledge conflict.
		Peripheral changes to T1		Sublating (T1&T2)		
				Supplanting (T1& T2)		
	Gamma	Accept the data and change of theory	Strong restructuring	Disregarding (T2)	Explicit knowledge building:	—*coherence*: seeks connections among pieces of information.
					New information is accumulated for constructing coherence in domain understanding	—*model comparisons:* identifies conflicting hypotheses for explaining the domain in question.

[1]Subjects can ignore the anomalous data being unaware of the contradiction they involve, or being aware of it, but putting the data aside.

Dreyfus et al., 1990; Baillo & Carretero, 1996; Guzzetti & Glass, 1993; Tillema & Knol, 1997; Limón & Carretero, 1997).

Nevertheless, some positive effects were also obtained. We will present some examples, most of them taken from recent literature. Dreyfus et al. (1990) reported some positive effects of conflict when both the conflict and the solution were meaningful for the student. Pearsall, Skipper, and Mintzes (1997) reported a substantial amount of knowledge restructuring in college-level biology students. Their results were obtained through a series of conceptual maps that students developed along the course (a semester's introductory university level course for science majors and non-science majors). Every four weeks the changes in the structural complexity of students' knowledge of biological concepts were measured using the successive maps that students elaborated. Their results indicated that: (a) growth in the structural complexity of students' knowledge is substantial and incremental along the course: accretion and tuning account for 75% of the changes observed; (b) this growth is significantly affected by the learning mode (meaningful vs. rote); (c) gender played a significant role, being favorable to females; and (d) incremental growth in structural complexity was concomitant with periods of both weak and strong restructuring. Changes involving superordinate concepts at the highest level were confined to the first 4 weeks of the course. Nevertheless, there is no description of the kind of teaching strategies employed along the courses, so it is not possible to know what teaching strategies were responsible for this weak and radical restructuring reported.

Jensen and Finley (1995) also reported some positive results after employing a "conceptual change strategy" to teach the Darwinian theory of evolution. Following the model proposed by Posner et al. (1982), they considered that the Lamarckian understanding of evolution could be a starting point to be challenged and replaced by the Darwinian theory. Therefore, they taught Lamarckian concepts before Darwinian ones so that students' initial misconceptions could be elaborated and consolidated, and then challenged by historically valid arguments. Students were provided with the Darwinian option for them to meet the conditions proposed by Posner et al. (1982): dissatisfaction, meaningfulness, plausibility and fruitfulness. The sample in the study comprised 42 college students enrolled in a course on the principles of biology. The course length was 10 weeks and each week students received two successive laboratory periods of 2 hours of instruction on the topic of evolution. The instruction given followed five steps: (1) general introduction to the nature of evolution; (2) teaching of Lamarckian principles; (3) teaching focused on evidence that opposed Lamarck's principles; (4) teaching of Darwin's theory of evolution; and (5) students' solving of evolutionary problems from both Lamarckian and Darwinian perspectives.

The pre-test–post-test comparison showed significant effects of the instruction. Even some of the initial worst responses became best responses (33% of initial worst responses became better responses). There was a 65% improvement in students' functional misconceptions. Although students were taught explicitly the Lamarckian view, they did not learn the "wrong" idea. Only 11% of the post-test responses were worse that the pre-test ones. The authors concluded that it seems that "if instruction recapitulates events in the development of the Darwinian theory of evolution in a way that meets conditions for conceptual change, then students replace their initial misconceptions with a more Darwinian conception" (Jensen & Finley, 1995, p. 164). Nevertheless, they noted two problems, despite the substantial improvement: (1) about 50% of the questions posed in the assessment instrument developed were not answered in strictly Darwinian way after instruction; and (2) there were key evolutionary concepts that remained difficult to understand.

Limón (1995, see also Limón & Carretero, 1998, 1999) presented contradictory information to two groups of individuals with high prior knowledge about the content of the historical problem presented to them. Thirty professors of history (all of them with a PhD and prior research experience on the topic of the historical problem presented) and 30 postgraduates finishing their MA degree in history participated in the study. Although no radical conceptual change was achieved, a positive effect of introducing anomalous data was obtained. Postgraduates realised that there were contradictions among the solutions they gave to the problem presented and the information presented, but most of them retained their initial ideas. However, the professors and some postgraduates made changes in their answers to give a wider explanation able to include both their initial ideas and the contradictory information. They reinterpreted the anomalous data incorporating them into their answers by making an extension of their initial hypothesis. Some of them were even able to make some peripheral changes to their initial hypothesis, but none of them were able to change their initial ideas in a radical sense. But what it is more interesting to note is that anomalous data made it possible to develop a more elaborate and sophisticated answer. Participants—mainly those with higher prior knowledge on the topic—used their knowledge to integrate the new data in their answers and contextualise them historically, discriminate levels of analysis (political, ideological, economic factors) or use the dimension of time to give an account of the conflicting information (distinguishing antecedents and consequences in the short, medium or long term).

Limón and Carretero (1997) also reported some positive effects of presenting conflicting data, even when students had almost no prior knowledge about the topic of the task presented. In this case, participants were 69 ninth-graders, 57 eleventh-graders and 63 twelfth-graders. The topic selected was the origin of organic life on Earth. Two experimental conditions were manipulated: (a) introducing conflicting data; and (b) anomalous and confirmatory data presentations. As expected, because of the low prior knowledge of the students, no weak or radical changes were made in students' ideas. Employing Piagetian terms (Piaget, 1975), only unadapted and alpha behaviours were shown. Nevertheless, when both confirmatory and contradictory information were presented, there were significant differences between ninth- and twelfth-graders: the younger the students were the least aware of contradiction. When only anomalous data were presented, there were no significant differences among the groups: almost all of them realised the contradiction. These results seemed to suggest some developmental differences. It was easier for older students to realise contradictions than the younger ones. However, introducing anomalous data seemed to help younger students to be aware of contradictions. If this is a first step, necessary but not sufficient to achieve conceptual change, it seems that to highlight clearly the differences between students' ideas and the new ones introduced by presenting conflicting data could help them to be aware of the differences between their own ideas and the ones introduced by the teacher, even if they have almost no knowledge about the topic taught.

On the other hand, presenting conflicting information helped students to reflect more about their ideas to give an explanation of the phenomena studied, and possibly this reflection could activate their curiosity about the phenomena taught. Even if no weak or radical change is produced as it was predicted, presenting anomalous data may promote the first steps of the process of conceptual change.

Recently, Mason (2000) also investigated the role of anomalous data in theory change on two controversial topics: the extinction of dinosaurs in the Cretaceous era and the construction of the great pyramids in Giza, Egypt. For both topics, eighth-graders were introduced to two theories, the first of which was familiar. For the extinction of the dinosaurs, the familiar theory was the meteor impact theory. For the construction of the great pyramids, the familiar theory was the classic theory. The second theory was an alternative one: the volcanic theory for the scientific topic and the theory recently proposed about a more ancient population who might have built the pyramids for the historical topic. For both topics, the introduction of the alternative theory was preceded by presenting evidence supporting it, but conflicting with the familiar theory. The findings indicate that acceptance of anomalous data made the most significant contribution to theory change. Students' theory change about the two controversial topics was strongly mediated by their response to anomalous data: the more they were considered as valid and incoherent with their current theory, the more they accepted the alternative theories. Students who discounted anomalous data, either by evaluating them as invalid or consistent with their familiar theory, were more likely to refuse the alternative theories. Acceptance of anomalous data was, in turn, weakly related, for the scientific topic, to the students' belief about the dimension of certain knowledge handed down by authority.

Mason (2001) has also qualitatively analysed the different types of reasons given by the students to justify the reasons they gave for accepting or refusing evidence conflicting with their current theory about the two topics. She found that the 24 reason types fitted into the revised taxonomy of responses proposed by Chinn and Brewer (1998).

Despite the positive effects we have reported, perhaps the most outstanding result of the studies using the cognitive conflict strategy is the lack of efficacy for students to achieve a strong restructuring and, consequently, a deep understanding of the new information. Sometimes, partial changes are achieved, but in some cases they disappear in a short period of time after the instructional intervention. Why are students so resistant to change even when they are aware of contradiction? Why are students able to partially modify their beliefs and theories but keep the core of their initial theory?

4. Why the cognitive conflict strategy seems not to work—at least to the extent it was expected—as an instructional strategy to promote conceptual change?

In our view, many of the difficulties found in the application of the cognitive conflict strategy in the classroom are closely related to the complexity of factors intervening in the context of school learning. Up to now, most of the theoretical models proposed to explain conceptual change focused mainly on the individual's cognitive processes, forgetting or, at least, not taking into account other individual's characteristics, such as motivation, learning strategies, epistemological beliefs, attitudes, etc., not including variables as important as the teacher and his/her features (motivation, teaching strategies, training, beliefs about what learning and teaching is, etc.) and social factors, such as the role of peers. Therefore, the cognitive conflict paradigm as an instructional strategy centered only on students' cognitive aspects neglects many other variables that influence students' learning in the school setting.

Owing to space limitations, we will focus only on some of the factors involved in the application of the cognitive conflict strategy in the classroom that may explain how it is not always effective, and we will try to integrate some of the theoretical problems into our review.

4.1. Difficulties to apply the cognitive conflict strategy in the classroom

Chan et al. (1997) indicated that it is necessary to distinguish between external and internal conflict. Often contradictory information is presented to produce cognitive conflict, but not so often that it achieves students involved in a knowledge-building activity (learner treating new concepts as something problematic that needs an explanation). In many cases, the introduction of anomalous data might only induce the new information to fit into the one they already have (direct assimilation), without achieving any cognitive conflict.

Dreyfus et al. (1990) reported that novices (16-year-old students) often failed to reach a stage of *meaningful* conflict. What the teacher considers meaningful for his/her students cannot be considered as meaningful for them. What is necessary for students to reach a stage of meaningful conflict? To consider new data or new information presented as meaningful, the problems and the topics introduced to students have to be relevant for them. That is, they need to feel curiosity and to be *motivated* about the learning activities. They also need to have a certain amount of *prior knowledge* to be able to understand the new information. The *learning strategies* students use to process the new information and to understand the task the teacher poses could also be relevant factors to promote a meaningful conflict. Students' *attitudes* and *epistemological beliefs* about learning and teaching and about the subject-matter introduced in the topic could help or hinder their view of the task introduced by the teacher as something meaningful. Also *discussion and work with peers* could help some students to look at the task introduced by the teacher as meaningful.

Students' *reasoning abilities* are also relevant for them to achieve a meaningful cognitive conflict. If students do not have the reasoning abilities necessary to solve the conflict, to distinguish between theory and evidence (i.e. Kuhn, Amsel, & O'Loughlin, 1988; Kuhn, 1991), to evaluate evidences or to realise that there are contradictory evidences, they will be unlikely to reach a meaningful cognitive conflict. It is well known how heuristics and biases are used to evaluate evidences. "My side" bias (i.e. Baron, 1995), the general trend to use verification instead of falsification (i.e. Evans, 1989; Gorman, Stafford, & Gorman, 1987; Beattie & Baron, 1988;

Kuhn et al., 1988; Koslowski & Maqueda, 1993) or the clear influence of motivational and emotional factors in reasoning (i.e. Kunda, 1990; Klaczynski, 1997; Zeidler, 1997) are good examples of how reasoning abilities are linked to individuals' beliefs and theories and of how motivational and emotional factors are often linked to both of them.

Therefore, if we expect students to achieve this first step (meaningful conflict) many variables have to be taken into account. To present just contradictory data that, often, from the students' point of view do not contradict anything or that are not interesting at all for them is not enough to lead students to a meaningful conflict. If this first requirement is not achieved, it is quite reasonable that students do not change anything at all. In order to achieve it, it is necessary to know more about all the variables we have marked in italics. We will present a brief overview of the current research about them and how they may explain why the cognitive conflict strategy was not as successful as expected in promoting conceptual change.

4.1.1. Motivational factors and conceptual change

Pintrich, Marx, and Boyle (1993) suggested that four general motivational constructs—goals, values, self-efficacy and control beliefs—are potential mediators of the process of conceptual change. Pintrich (1999) suggests that a mastery goal orientation, adoption of constructivist beliefs about learning, higher levels of personal interest, self-efficacy and personal control will facilitate conceptual change.

Cognitive conflict strategy demands from the students a higher level of cognitive engagement than more traditional instructional strategies. As Pintrich remarks, motivational beliefs may not have a direct influence on conceptual change, but as theories or beliefs about the self and about learning, they may influence the process of belief formation that takes place when students acquire new knowledge or, in our case, when they are presented with new information that contradicts their prior conceptions. They also may be involved in the degree of cognitive engagement students may reach. In our view, it is extremely important to highlight that these motivational traits and beliefs are *extremely dependent on the classroom context*, rather than on individual traits only.

Pintrich and García (1991) and Pintrich, Smith, Garcia, and McKeachie (1993) have found that college students' self-efficacy beliefs about their performance in a college course are strongly related to their use of cognitive and metacognitive strategies in the course, as well as their actual performance. The use of these strategies seem to make students more confident in themselves and may lead them to a deeper processing of the information as required by the cognitive conflict strategy.

On the other hand, a more constructivist learning view (students' epistemological beliefs) seems to be linked to a deeper processing of the new information too, to a wider application of cognitive and metacognitive strategies, to a higher level of cognitive engagement and, depending on the classroom context, may facilitate a student's mastery goal orientation. These results show how motivational factors are closely related to other factors we have named above: students' application of more developed learning strategies (self-regulated learning strategies), epistemological beliefs, reasoning strategies, students' attitudes towards learning and teaching, etc.

As most of them are highly dependent on the classroom context, it will be necessary to study them in relation to it and to clarify their relationships in order to create appropriate learning environments in which the cognitive conflict instructional strategy will be successful.

It is extremely important not to forget that instructional strategies should increase students' capabilities to apply their cognitive and metacognitive strategies and their self-confidence in their possibilities to accomplish school tasks. As Pintrich (1999) says: "it is not useful for teachers to create tasks that increase the opportunities for cognitive conflict and then leave students entirely to their own devices to resolve the conflict. Students must be assisted in their learning how to resolve cognitive conflict through both modeling and scaffolding".

4.1.2. Students' prior knowledge

Chinn and Brewer (1993) considered the characteristics of prior knowledge as one factor that influences people's responses to anomalous data. Among these characteristics, they highlighted how entrenched the prior theory is, the influence of ontological and epistemological beliefs, and students' background knowledge. If students have little or no knowledge about the topic, it is difficult to expect any change because their understanding of the new information may be so minimal that the conflict is not meaningful at all. In fact, when their prior knowledge is almost none, they are probably not able to recognise it (Limón & Carretero, 1997). How entrenched their beliefs, concepts or theories are may also be relevant. For example, Vosniadou (1994) pointed out that conceptual change is harder when students' ontological beliefs need to be changed, because these beliefs are much more entrenched.

From our point of view, prior knowledge is a key aspect to implementing successfully the cognitive conflict strategy in the classroom. If we do not know deeply students' prior knowledge and how to activate it, and we are not able to develop efficient assessment tools, how could we measure and define conceptual change if the starting point "A" is still a big unknown, and how could we induce a meaningful conflict that seems to be a necessary first step for the conceptual change process?

Misconceptions and students' ideas about scientific phenomena have been studied extensively but most of these studies are related to science. But are the features attributed to misconceptions in science the same in other subject-matter domains? The questions about stability, coherence and universality of misconceptions in the domain of science are still unanswered. Some theoretical models of conceptual change have tried to describe features of this prior knowledge (i.e. Vosniadou & Brewer 1987, 1992; Vosniadou, 1994; Chi, 1992; Chi et al., 1994; diSessa 1988, 1993), but there is a lack of precision, in our view, to clarify what we are talking about—ideas, beliefs, theories, misconceptions, preconceptions, mental models, students' misunderstandings or failures to learn something.

Although this is a theoretical problem researchers are faced with, it may explain some of the difficulties in applying the cognitive conflict paradigm in the classroom. Methodological problems associated with assessing students' prior knowledge should be added. For us, having still just such a little knowledge about students' prior knowledge, it is not strange to find controversial results about the efficacy of this paradigm.

This does not mean that it is impossible and not useful to apply some of the research advances in the classroom, but only not to have expectancies that are too high and think that further basic and applied research is needed before one is able to develop more successful teaching strategies. On the other hand, it should not be forgotten that there is a large gap between research and tools developed for research and the application of these tools and research results in the classroom.

Another controversial issue is what should be understood by "conceptual change" (weak restructuring, strong restructuring, discrimination of contexts where different representations need to be used)—in other words, what will be the goal to be achieved by students? If we have represented by "A" the starting point, that is prior knowledge, "B" will be the opposite extreme of the conceptual change process. What degree of conceptual change is it intended that students should achieve?

The idea of replacement of the old beliefs, concepts or theories by the new ones as the final goal of the process of conceptual change, which is explicitly or implicitly included in most of the conceptual change models proposed, was criticised by some researchers (i.e. diSessa, 1993; Spada, 1994; Pozo, Gomez, & Sanz, 1999; Caravita & Halldén, 1994; Halldén, 1999). For example, diSessa (1993) said that intuitive knowledge has to be reused and integrated to achieve scientific understanding. For him, "building a new and deeper systematicity is a superior heuristic to the 'confrontation' approach many theorists have taken" (p. 51). The knowledge fragments that constitute intuitive physics do not have to be attacked, but rather used to develop scientific understanding. Caravita and Halldén (1994) and Spada (1994) pointed out that old beliefs do not have to be replaced. In particular, they think that misconceptions are very predictive and useful in daily life, so they do not have to be abandoned. Then, the learning goal would be to teach students to determine which concepts and problem solving strategies are adequate in which situation. According to Spada (1994), promoting multiple mental representations does not require the assessment of each student misconception which might be neither necessary nor helpful.

Even if these criticisms—which we agree with—are accepted, a kind of revision or restructuring of students' ideas has to be achieved even if they maintain multiple representations adequate for different contexts. Even if they do not abandon their old conceptions, they need to make changes in their conceptual network to discriminate which concepts or representations are adequate in which situation. Maybe the coexistence of representations could be the final product of a process of cognitive conflict. For us, cognitive conflict is a first step for any change or restructuring of students' beliefs, concepts or ideas, even if it is true that for this conflict to be so (to be meaningful) we have to take into account motivational and affective factors, students' epistemological beliefs, prior knowledge, etc. For students to understand the new information introduced by the teacher, they have to realise (be aware) that there are differences, and probably also similarities, between their knowledge and the new information they have to learn. For us, this phase of being aware of the differences and similarities brings about a "conflict" they have to solve. Synthetic models obtained by Vosniadou (1994) could be an example of a kind of solution.

Understood in this way, conflict does not involve fronting students' initial beliefs, concepts or theories with the new ones to replace them. Awareness of conflict would be a first step of a process of integrating the new information. In some cases, the process of conceptual change can stop with an understanding of the new information, although its implications for one's beliefs are not considered as the level 3 of contradictory information processing proposed by Chan et al. (1997, see Table 1). In other cases, it can lead to a radical restructuring or, sometimes, the process can stop with a weak restructuring. Conceptual change is a gradual process and not an "all-or-nothing" process. Therefore, in general, a dramatically radical change cannot be expected just after introducing anomalous data in a short instructional intervention. Nevertheless, it would be necessary to know in more detail how much time instructional interventions should take to be effective in promoting the degree of change desired. This will have important implications for curriculum design.

4.1.3. Students' epistemological beliefs

Together with prior knowledge on the topic involved in the tasks proposed, students also have epistemological beliefs about the subject-matter and about learning and teaching that seem to facilitate or to hinder conceptual change (see Hofer & Pintrich, 1997, for a comprehensive review).

Hammer (1994) showed that students (n=6, freshmen) in an introductory physics course have beliefs about knowledge and learning that are involved in their work. For example, according to his conclusions, some students' knowledge remained fragmented in part, because they did not expect to be coherent. Or some misconceptions were retained because, in part, they did not think conceptual knowledge was essential or because they did not think they should try to modify their own understanding. An awareness of these beliefs might help with decisions in the classroom or provide insight for instructional design.

The interaction of epistemological beliefs with achievement is also reported by Windschitl and Andre (1998). They found that students (n=250, freshmen and sophomores) with more sophisticated epistemological beliefs (measured with the questionnaire elaborated by Schommer, 1993) performed better in a constructivist learning environment, where they were allowed to explore a computer simulation of the human cardiovascular system, than when they worked with the simulation following directive instructions which did not allow them to explore it. Students with less sophisticated epistemological beliefs (knowledge is simple and certain) performed better in the directive learning environment than in the constructivist one. The exploratory learning approach, like the constructivist one, may have induced more positive motivation for learning in the students with more sophisticated beliefs and more negative motivation for those with less sophisticated epistemological beliefs.

In Mason's (2000) study mentioned above, for the topic of dinosaur extinction, the eighth-graders who believed in the changing nature of knowledge tended to accept evidence conflicting with their entrenched conceptions and, consequently, to change their theory about the topic. In contrast, those who believed in the static nature of knowledge tended to discount, in one way or another, anomalous data and remain attached to their current theory. Several students appealed to their epistemological belief in the scientific authority as a source of knowledge both for accepting the anomalous data (as the product of the work made by very qualified people) and for not accepting (even scientists can be wrong). Moreover, some students showed a strong affective involvement with the meteor impact theory on dinosaur extinction. They admitted that the anomalous data could be valid and inconsistent with their held theory, but they could not renounce their deep "attachment" to that theory (Mason, 2001).

It has also been investigated whether there are developmental changes in students' epistemological beliefs. The findings from the studies by Schommer (1993) and Schommer, Calvert, Gariglietti, and Bajaj (1997) on secondary students' beliefs about the nature of learning and knowledge indicated that there are substantial differences in students' epistemological beliefs across the high-school years. Alexander, Murphy, Guan, and Murphy (1998) also found developmental differences. These authors think that it may be unlikely that students engage in the effort required to alter understandings that are valueless or unimportant from their view. It would be equally unlikely that those who hold an understanding as a belief, however misconceived, would permit themselves to be persuaded to rethink their understanding. So for them, conceptual change may be probable only when the concept in question falls within that overlap between knowledge and beliefs. Conceptual change would be achieved better when the learner believes that an idea is not only plausible but also has some personal value.

4.1.4. Students' values and attitudes

This *personal relevance* also seems to be a very important factor in leading individuals to a meaningful conflict and in making the effort necessary to modify their understanding. This resistance to change personal beliefs that are involved in their understanding and in their achievement may explain, in part, the lack of efficacy of many of the instructional strategies employed to promote conceptual change. It seems that to consider the possibility of changing, it could be necessary sometimes to change *students' attitudes*. In this sense, Kuhn and Lao (1998) have pointed out the need to connect the field of conceptual change with the field of belief change of the social psychology. Sinatra and Dole (1998) applied the elaboration likelihood model (ELM) proposed by Petty and Caccioppo (1986) to explain some of the difficulties in achieving conceptual change. Under conditions of high elaboration that occur when individuals engage in a thoughtful, effortful processing of arguments, a change in beliefs can occur. This route to persuasion is called the central route and may lead to a permanent change in beliefs. On the contrary, when individuals do not engage in a thoughtful, effortful processing (a low elaboration situation), a change in beliefs may also occur, but in this case individuals attend to peripheral cues that prompt a heuristic processing of information. This heuristic processing triggers a rapid global evaluation that may lead to temporary changes in beliefs that, over time, dissipate. This is called the peripheral route to persuasion.

The central route is compared to a process of conceptual change learning (Dole & Sinatra, 1998). To achieve this permanent change in beliefs, individuals should: (a) be motivated, that is, topics should have personal relevance for them and they should have a high need for cognition (need to structure relevant situations in a meaningful way); (b) possess enough background knowledge; (c) have sufficient cognitive ability to process the message; and (d) be given comprehensible information. Under conditions of low elaboration, learners are less likely to change. To achieve a permanent change of belief is difficult, according to the ELM. Nevertheless, a temporary belief change may be achieved according to a variety of peripheral cues. For example, even when individuals are not motivated, they can be persuaded by using peripheral cues such as credible and attractive contexts. These temporary change of beliefs could be the reason why under some attractive contexts students can convince their teachers they have changed their beliefs. Sinatra and Dole (1998) highlighted the fact that the ELM explains students' motivational and affective responses as well as the necessity for a deep processing for learning to occur. One of the ELM's advantages is that the effect is considered to be multidimensional and this may help to explain students' different reactions and behaviour when they are have new conflicting information.

4.1.5. Students' learning strategies and cognitive engagement

This need for a deep processing is also mentioned by Chinn and Brewer (1993) as a factor that will influence individuals' responses to anomalous data. Chan et al. (1997) carried out a study to explore how individuals and peers process scientific information that contradicts what they believe and assessed the contribution of this activity to conceptual change. Participants (54 ninth-graders and 54 twelfth-graders) were assigned to four conditions: (a) individual conflict; (b) peer conflict; (c) individual assimilation; and (d) peer assimilation. Depending on the condition they were assigned, students were asked to think aloud or to discuss with their peers eight scientifically valid statements that were presented in a certain order to maximise or minimise the conflict. They proposed that the contrasting approaches of direct assimilation and knowledge building provide a framework to explain the persistence of naive conceptions and the achievement of conceptual change. Direct assimilation involves fitting new information directly into existing knowledge. Knowledge building involves learners treating new concepts as something problematic that needs to be explained (Bereiter & Scardamalia, 1993). These learners are more likely to engage in conceptual change because they engage in an ongoing process of problem recognition and conflict resolution.

Their results showed that when conflict was maximised, students performed better. This result is consistent with the idea of generating conflict to promote conceptual change. But when students' knowledge-processing activity was included in the analyses, the effect of conflict on conceptual change increased only when there was an increase in knowledge-building activity. The path analysis they performed indicated that conflict may trigger knowledge-building activity and then lead to conceptual change. But *conflict in the absence of knowledge-building activity will not produce conceptual change*. These results clearly indicate the importance of students' learning and processing strategies. This deep processing or knowledge-building activity seems to be closely related to motivation, epistemological beliefs, metacognition and self-regulated learning (Beeth, 1998; see Hartman, 1998, for a review about metacognition and Pintrich, 1995, for a review about self-regulated learning).

4.1.6. Social factors: role of peers

Regarding the role of peer collaboration on processing contradictory information, Chan et al.'s (1997) findings were that not all the students benefited from peer collaboration. Their results indicated that the effects of peer collaboration may vary depending on the group processes. In their case, older students facing maximal conflict were more likely to employ more sophisticated discourse processes. Older students performed better in the peer condition whereas the younger did better in the individual condition. Also students in the conflict condition benefited more from peer collaboration than in the assimilation condition.

Mason (1996, 1998) and Mason and Santi (1998) found that students (fifth-graders in the three studies) benefited from classroom discussions which helped them to review their ideas and to build up new concepts. The authors highlighted how collaborative discourse-reasoning can help students to gradually master scientific understanding.

Dunbar (1995) studied the use of inconsistent evidence (anomalous data) by scientists working on their own experiments. First, inconsistent evidence was used to change some features of a specific hypothesis, but maintain the same overall hypothesis. Second, when scientists needed to create a new hypothesis to explain anomalous data, they did it working in a group. In particular, when unexpected findings occurred and the researcher believes that these findings were not due to error and other members of the group challenged the researcher to interpret the anomalous data, significant conceptual change occurred. Question answering was a potent mechanism to induce conceptual change. Discussion in the group can induce the adoption of new perspectives and goals that can facilitate the reorganisation of knowledge.

Nevertheless, the role of social aspects in promoting conceptual change has received some critiques. For example, Kelly and Green (1998) noted that arguing a position is not the same as changing one's conceptions. When students are participating in classroom discussions and adopt a view, are they changing their concepts, reconstructing their knowledge or merely expanding their repertoire for participating within a social setting? Chinn (1998) considered that social factors, cognitive factors and nature interact to shape the outcome of five scientific processes: choosing a topic, observing, inferring phenomena from data, generating a theoretical interpretation and deciding what interpretation to believe. For him the role of social world is much greater among children than among scientists. The main social process involved in knowledge change in science students is the acceptance of ideas based on trust or authority. Further research to clarify the role of peers in the processes of conceptual change is needed. Although for us conceptual change is a cognitive individual process, it seems clear that social factors may help to promote awareness of one's own beliefs, and therefore awareness of a possible conflict (understood as a recognition of differences and similarities between one's own beliefs and the new information) which in turn may lead to a solution which implies some degree of conceptual change.

4.1.7. Students' reasoning abilities

As we have indicated above, students' reasoning abilities and how they use them to evaluate evidence are also relevant factors in promoting a meaningful cognitive conflict. As Zeidler (1997) remarked, students are not always required to challenge their core beliefs when they are confronted with contradictory or competing claims. Topics or arguments chosen may not even scratch their "protective belt" because of a lack of relevance or interest or because they do not have sufficient prior knowledge on the topic to evaluate the evidence presented, and perhaps to realise the contradiction between the pieces of information given. Koslowski and Maqueda (1993) stated that "for confirmation and disconfirmation to be significant, a hypothesis must be tested not merely against alternative hypotheses, but against alternatives that are plausible. And this bring us to the role of theory, because it is background theories . . . that render alternatives either plausible or not" (p. 113).

In these cases, according to Zeidler, students' acceptance of new information or their attempts to explain conflicting data may have less to do with protecting a core belief than what it is considered as reasonable evidence. Often, they commit the fallacy of hasty generalisation: they prematurely assert, accept or refute a generalisation on the basis of an inadequate sample (too small, not random, not representative, etc.). The wide literature about heuristics and biases illustrates how content, context, motivational and affective factors influence students' reasoning. But also a lack of training or capability in reasoning abilities such as argumentation or hypothesis testing, among others, may add difficulties for students to recognise and/or to be able to solve conflicts. Developmental differences in these reasoning abilities which allow students to recognise and solve a conflict may also be present and should be explored in depth.

5. Conclusions

From our point of view, three kind of problems might explain why the cognitive conflict strategy is not as successful as expected when it is implemented in the classroom to promote conceptual change. The first group deals with the question of how to make the cognitive conflict meaningful for the students, which seems to be the first step in a successful implementation of this strategy. The second group refers to general theoretical problems that the research on conceptual change still has to solve, but which are central to improve the application of this strategy in the classroom. The third group refers to practical problems of the implementation in the classroom of the conceptual change strategies, and particularly the cognitive conflict one has.

Most of the problems of the second and third groups are not specific to the cognitive conflict strategy and, therefore, they may also be applicable to other conceptual change instructional strategies.

5.1. How to induce a meaningful cognitive conflict?

Cognitive conflict seems to be a starting point in the process of conceptual change. To start the process of change, this conflict has to be meaningful for the individual.

The lack of meaningfulness may explain some of the difficulties that the cognitive conflict strategy has had when it has been implemented in the classroom. To induce a meaningful cognitive conflict, students should be motivated and interested in the topic, activate their prior knowledge, have certain epistemological beliefs and adequate reasoning abilities to apply. It is not easy to have all these aspects, but they seem to constitute the first necessary condition for the cognitive conflict strategy to work. On the other hand, the strategy of presenting anomalous data or contradictory information was often considered the only or the best way to induce cognitive conflict. The introduction of anomalous data is one strategy to provoke cognitive conflict, but not the only one. Perhaps analogies and metaphors or a discussion with a partner or in a group may lead a student to a meaningful cognitive conflict. From a teaching perspective, what seems to be the starting point to promote any change in the conceptual network is to lead the individual to be aware of the differences between their own beliefs, concepts or theories and the new information. Table 2 summarises the variables we have reviewed that might contribute to inducing a meaningful cognitive conflict.

5.2. Conceptual change theoretical problems

If a rather simple representation of the conceptual change process is used, "A" being the learner's prior knowledge and "B" the goal or degree of change to be achieved, it can be said that further clarification of what is understood under the label "prior knowledge" is needed. In addition, and depending on this starting point relative to prior knowledge, it is necessary to define the goal more accurately: what

Table 2
Variables that might contribute to inducing a meaningful cognitive conflict

Variables related to the learner	Prior knowledge Motivation and interests Epistemological beliefs (about learning and teaching and about the subject-matter to be learned) Values and attitudes towards learning Learning strategies and cognitive engagement in the learning tasks Reasoning abilities
Variables related to the social context in which learning takes place	Role of peers Teacher–learner relationships Teacher–learners relationships
Variables related to the teacher	Domain-specific subject-matter knowledge Motivation and interests Epistemological beliefs about learning and teaching and about the subject-matter taught Values and attitudes towards learning and teaching Teaching strategies Level of training to be a teacher

degree of change and what type of change are expected from students. It is especially important for its instructional implications to know more about the intermediate steps that follow the initial step of meaningful cognitive conflict, and not to assume that this process is necessarily linear. A more detailed, although rather summarised, agenda follows.

- Most of the models reviewed centered on individual's cognitive processes. Future models will have to take account of social and affective factors, students' epistemological and ontological beliefs, learning strategies students might activate, etc. Further research is needed to study in depth the influence of all these factors independently and the interaction between them.
- Most of the research conducted has referred to science learning and teaching. It is necessary to investigate other subject-matter domains to have more general models able to predict conceptual change in other knowledge areas.
- Many factors influence only individuals' awareness of conflict. To achieve a radical restructuring or a radical conceptual change probably involves changing not only cognitive but many aspects (i.e. epistemological beliefs, motivation, learning strategies, etc.). Therefore, we question whether "conceptual change" is still a good label to take account of the changes and processes that take place to achieve a radical conceptual change.

In the conceptual change literature, it is often found that concepts, beliefs, conceptions, ideas, prior knowledge, background knowledge, theories, mental models, etc., are to be changed, but the same terms are used with very different meanings and there is no general consensus on defining more accurately the meaning of all these terms. The same question arises again: is "conceptual change" still a good label? If so, what should be understood by "conceptual change"?

- In general, the models of conceptual change that have been proposed have a linear view of the process of conceptual change. Nevertheless, it could be suggested that perhaps this process might have curves, not always being linear. We still lack a more accurate knowledge of the intermediate states of the conceptual change process. To investigate these intermediate steps is particularly interesting and necessary in the case of the cognitive conflict strategy. Which steps do individuals follow once a meaningful conflict is achieved until they are able to make a radical restructuring of their prior knowledge? Although we have some theoretical frameworks (summarised in Table 1), further research is needed. How domain-specific features influence these intermediate steps is still unknown and requires more research.
- One of the major problems the research on conceptual change has to solve in the future concerns the learner's *prior knowledge*. What knowledge is activated by each student when they are presented with a learning task? How do we assess prior knowledge? More refined methodological tools should be developed to take account of the learner's prior knowledge.

These problems and others that undoubtedly could be added need to be investigated in greater depth in order to understand what limits conceptual change in the classroom.

5.3. Problems of implementation of instructional strategies developed to promote conceptual change

In general, most of the analyses performed to evaluate the efficacy of conceptual change instructional strategies look at the learner but not at the teacher. Apart from the theoretical problems, it is important not to forget that the implementation of conceptual change instructional strategies takes place in a real setting. The success of the implementation also depends on the teacher. Weaver (1998) pointed out that teachers should be provided with training to act as facilitators of discussions on the implications of conflicting data and to be able to bring cognitive conflicts to light. He stressed that teachers often do not have first-hand experience of real scientific inquiry and so it is difficult for them to know the difficulties and demands associated with it. Moreover, many teachers feel insecure in promoting discussions in the classroom because they are not confident in their mastery of the subject-matter content. Weaver (1998) also pointed out how an excellent strategy to promote conceptual change might fail and reduce teachers' motivation if they only have 50-minute class periods which can be insufficient to develop the activities planned or if they are pressed to cover the subject program.

Tillema and Knol (1997) carried out a program to stimulate prospective teachers to explain their beliefs, search for new knowledge, and enact what they learned in their teaching practice. Contrary to what it was expected, the conceptual change approach program was not successful in promoting higher levels of reflectivity in prospective teachers. This program was not enough to change their beliefs. Even if they were able to teach according to the teaching approach they were taught (conceptual change versus more traditional direct instruction), their beliefs did not change. About half of the participants (n=68) shifted during the implementation of the program to think that they were not well prepared to enact the teaching behaviors they were called for, showing stress reactions. Teachers might believe that instructional strategies suggested to promote conceptual change are rather demanding and slowly implementable, and require many actions they do not feel prepared for.

Although this cannot explain the failure of instructional strategies to promote conceptual change in the context of research, it might be a very relevant factor for a successful implementation of these strategies. On the other hand, teachers epistemological beliefs about learning and teaching in general and about the subject-matter they teach should also be taken into account as a possible obstacle for the effective implementation of conceptual change strategies in the classroom.

Villani (1992, p. 233) questioned whether conceptual change—understood as radical change—is a viable objective at every school level:

> Many questions seem to have remained unanswered until now. For example: is conceptual change a viable objective at every school level? Or should we seek less dramatic and more accessible goals at the end of the science course? Are

some teaching methodologies and strategies really more efficient than others pursuing these aims? Is it possible to draw up any general conclusions concerning the practice of conceptual change?

How long could it take to induce a meaningful cognitive conflict? How long could it take for each student to achieve a particular degree of conceptual change? Under the real conditions of the school settings, to what extent can the cognitive conflict strategy or other conceptual change instructional strategies be applied successfully? These and more questions can be added to those raised by Villani.

Radical conceptual change involving a radical restructuring could be a goal for some contents to be achieved along some academic years, and as the final goal of a wider educational period (i.e. primary school or secondary school). Different degrees of understanding could be different goals to be reached along the academic curriculum. For example, the degree of understanding of the concept of "force" that a secondary school student should have is quite different from the level demanded in a science major course at university. In this sense, a more accurate knowledge of the intermediate states between novices and experts could be very helpful in suggesting possible sequences to introduce the disciplinary contents.

As a general suggestion, perhaps a better balance between the requirement of covering programs and the achievement of understanding and meaningful learning would be advisable. If teaching focused mainly or exclusively on meaningful learning achievement, then content would have to be dramatically reduced and this is in contradiction to what many educational systems and parents still ask of the school.

Acknowledgements

The author thanks Lucia Mason for her patience and helpful comments on the first draft of this paper, the CIDE (Spanish Ministry of Education) for funding the research project on "Motivation and conceptual change in different subject-matter domains" led by the author, and her undergraduate students for their support and helpful questions.

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