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Conceptual Change and Dissonance**

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**Abstract:** A problem in our field is that conceptual change is a term that has several different meanings. Disparities also occur with respect to the meanings of the terms 'conflict', 'disequilibrium', and 'dissonance'. In addition, as the strategies aimed at conceptual change have evolved, the same terms have taken on new meanings and some new implicit distinctions have emerged. The goal of this paper is threefold: 1) to present a brief review of the evolution of conceptual change concepts, 2) to propose some additional distinctions and attempt to define terms for them in a consistent way, and 3) to review articles that portray different roles dissonance plays in conceptual change strategies. It is our hope that developing a somewhat richer set of differentiated concepts will lead to better discussion and communication. The processes of conceptual change may occur as a result of theoretical or empirical stimuli originating internally within the student and externally from other students, the teacher or from observations. However, whatever the source or outcome, based on our review, it may be that dissonance is to some extent unavoidable in learning situations where a prior model exists. Dissonance could provide a useful tool in promoting conceptual change when used with care. An important question is the optimal level of dissonance for effecting conceptual change under different circumstances. Therefore, it is important to look for optimal ways to use dissonance before dismissing it as a strategy.

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**Teaching For Understanding, Part I:  
Concepts of Conceptual Change and Dissonance**

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**Completion date: 8-21-97**

**ABSTRACT**

A problem in our field is that conceptual change is a term that has several different meanings. Disparities also occur with respect to the meanings of the terms 'conflict', 'disequilibrium', and 'dissonance'. In addition, as the strategies aimed at conceptual change have evolved, the same terms have taken on new meanings and some new implicit distinctions have emerged. The goal of this paper is threefold: 1) to present a brief review of the evolution of conceptual change concepts, 2) to propose some additional distinctions and attempt to define terms for them in a consistent way, and 3) to review articles that portray different roles dissonance plays in conceptual change strategies. It is our hope that developing a somewhat richer set of differentiated concepts will lead to better discussion and communication.

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## **INTRODUCTION**

A review of the literature reveals a pattern inherent in most studies of conceptual change. These studies appear to begin with the belief that students come to the classroom with many preconceptions, sometimes referred to by researchers as alternative conceptions, misconceptions, or naive conceptions, and that these preconceptions are resistant to change. It is from this premise that researchers have developed strategies to foster and encourage conceptual change. These strategies in turn, have often driven the definition of terms. Our own definitions will be discussed in detail later.

The strategies are most often based on a Piagetian theory of cognitive development in which disequilibrium, dissatisfaction or discord within the individual, must be created between the initial conception of the child (one not in line with scientifically acceptable facts) and the conception to be taught. From this inception, numerous strategies have been proposed, from strict elimination of prior conceptions, to development of dual conceptions operating at various times within the same person as dictated by the situation. In other situations the alternative conception is left unchanged but new knowledge is separately constructed by the individual. In addition, there is the question of whether we can say that conceptual change is occurring when there is no substantive alternative conception in existence. For the purposes of this paper, we will concern ourselves only with those instances where an existing conception is present or is formed during teaching.

Numerous theories exist concerning how conceptual change actually occurs. We will review some of these so as to more fully understand how the vocabulary developed. The work of Vosniadou & Brewer (1987) stated there

were actually two types of restructuring which take place during conceptual change. The first, weak restructuring, allows new information to be accumulated and new relationships to occur between existing ideas, without change to the core concepts. This is similar to Piaget's assimilation where new information is integrated into an already existing schema without the necessity of overhauling the basic conception. However, for the second type of restructuring, radical restructuring, to occur, a change in core concepts and structure of knowledge must take place.

Duit (1995) suggests that conceptual change has to do with restructuring what is already known. This view is supported by Piaget, Toulmin (1972), and Jung (1993). Another view was posed by Linder (1993) and Marton (1981) in which they stressed that new ideas are related to the context in which they are used. Marton stated that conceptual change is achieved through an enlargement in context rather than a change in the concept. However, Hewson & Hewson (1992) suggest that it is a change in the status (significance a learner assigns a conception) given a conception that allows for a change in the concept rather than just a change in context.

The two categories of weak and radical restructuring were supported by the work of Duschel (1992) who further emphasizes that radical restructuring requires the learner to acquire new procedural knowledge with which to reevaluate existing knowledge before change can occur. Therefore, if students do not have the necessary knowledge base or factual information needed to critically evaluate their existing knowledge, then this radical restructuring may not occur. Still others state that conceptual change occurs when there is a gradual introduction of the necessary new information, reinterpretation of existing alternative conceptions and exposure to new models that does not promote extinction of the old conception (Vosniadou, 1994; Caravita & Hallden, 1994; Grandy, 1990).

Clearly, conceptual change has been described in a variety of ways. For purposes of this paper, the most useful path for us has been to use conceptual change to refer to situations where a significant new cognitive structure is created - a change that is structural or relational in character. This might happen by modifying a prior conception or model used to understand

the target domain, or it might happen by constructing an independent new conception or model. This is compatible with the terminology used by Thagard (1992). For the purposes of this paper we will also use the following definitions:

'Preconception' refers to a conception held prior to instruction in a particular topic.

'Alternative conception'(misconception) refers to those conceptions that are incompatible with currently accepted scientific conceptions.

'Naive conception' refers to those conceptions students hold that, while not incompatible with currently accepted theory, are simplistic conceptions that are not scientifically complete from an expert's view.

'Prior model' refers to either an alternative conception (misconceptions) and naive conception or an intermediate model, as developed during instruction, that the student brings to the learning situation.

We find these categories useful even though they are not mutually exclusive.

In this paper we will focus on cases where the student has a prior model that provides an interpretation of a target problem or domain. We will also make the simplifying assumption that during learning, the prior model is either eliminated, transformed to a different schema, or left untouched. diSessa (1988) has argued that other changes of a more subtle and intermediate nature can occur (such as a change in the conception's priority or range of application). This and other more complex models of such cases will be left for future research to consider.

### **EARLY WORK ON CONCEPTUAL CHANGE**

The earliest literature on conceptual change centered on cataloging students' "scientific misconceptions"; that is, what children actually believed about a subject (Viennot, 1979; Driver, 1973; Nussbaum, 1979; Nussbaum &

Novak, 1976). As researchers then began to look at how one would go about helping students move from their misconceptions to a more scientifically accepted conception, they relied initially on Piaget's theory of disequilibrium in which assimilation and accommodation play major roles. Researchers believed that in order for change to take place, disequilibrium in the form of dissatisfaction with the current model must occur (Posner, Strike, Hewson, and Gertzog, 1982). They further believed that once dissatisfied, the student must see the new concept as intelligible, plausible, and fruitful. The student may also need to make changes to other related schemata.

What follows is a discussion of some of the ensuing methods employed in conceptual change research. We will attempt to trace the role of dissatisfaction in these theories of conceptual change.

### **ELIMINATION OF ALTERNATIVE CONCEPTIONS**

Thus, it is the issue of dissatisfaction that gave rise to the early models of conceptual change. If one were to attempt to change the alternative conception held by a student, it was believed that one would first extinguish the alternative conception in order to then substitute new conceptions (Nussbaum & Novick, 1982; Duit, 1995; Gorsky, 1994). The strongest point of view is that when presented with an anomaly, the learner would change their thinking about a concept to accommodate the new information. Discrepant events were often used early in the learning experience to provide an anomalous situation, one in which an event was presented that was contrary to the student's expectations (Driver, Guesne, & Tiberghien, 1985).

Gorsky & Finegold (1994) contended that the degree of disequilibrium from a discrepant event shown by a computer simulation could vary greatly over different examples. Some were powerful in stimulating conceptual change while others appeared to have no effect. The degree to which the disequilibrium caused the student to modify existing schemata appeared to be an underlying factor. Minor disequilibrium was equated with minor schemata changes, while more extreme disequilibrium was associated with either restructuring schemata or totally rejecting the anomalous data.

Driver, et al (1985) stated that "simply noting a discrepant event, however, is not necessarily followed by a restructuring of that student's ideas--such restructuring takes time and favorable circumstances." This disequilibrium did not always lead to conceptual change. It was often found that students did not readily give up their prior conceptions to accommodate the new information, but rejected this new conception, or accepted it as a concept to be used in certain "school" situations while retaining their initial conceptions for "real world" situations. In fact, in Gorsky & Finegold's computer simulations of discrepant events, students found some events so incompatible with their prior conceptions, that they questioned the reality of the computer generated simulation.

According to Posner et al. (1982) the use of anomalies to cause dissatisfaction with an existing conception only works when "students understand (a)why the experimental findings represents an anomaly, (b)that it is necessary to reconcile the findings with their existing conceptions, (c)are committed to the reduction of inconsistencies among the beliefs they hold, and (d)attempts to assimilate the findings into the students' existing conceptions are seen not to work." Since meeting all of these conditions is difficult at best, the authors suggest that rather than leading to conceptual change, anomalies might just as well lead to rejection of a theory or compartmentalization of knowledge to prevent a conflict from arising.

Chinn and Brewer (1993) actually delineate six possible reactions to contradictory information which can occur other than an change in conception. These include the student ignoring the data, rejecting it out right, excluding the data, holding it in abeyance, reinterpreting the data, or accepting the data only for making peripheral changes in their prior conception. Only their seventh reaction results in conceptual change.

In their review of conceptual change, Scott, Asoko, and Driver (1991) separate the use of discrepant events from other forms of inducing conflict, making the case that, historically, the intent of discrepant events was to eliminate the student's prior conception. Then a new conception could be introduced as a replacement. Duit groups all forms of conflict promotion together, whether discrepant events or conflict induced through open-ended

questions, predictions, and contrasts between teacher and students or student and student. Duit then goes on to warn that while the teacher may recognize the intent of the discrepant event, the student may not see the conflict at all.

In summary, early conceptual change theory relied heavily on discrepant events as a means of not only causing dissatisfaction with a conception but causing such strong dissatisfaction that the students were willing to give up their initial conception entirely. The cause of this dissatisfaction was labeled conflict. This poses a theoretical problem. Conceptual change was thought to require conflict caused by discrepant events. But are there other means of initiating dissatisfaction which do not rely on either discrepant events, harsh conflict, or imply the elimination of prior conceptions?

#### **FROM ELIMINATION TO BUILDING ON PRECONCEPTIONS**

These questions were partially answered when attempts at conceptual change through discrepant events were modified by later researchers who included strategies that, while still providing contrast between conceptions, also drew on what the student already knew and believed. Stavey & Berkovitz (1980) use the term cognitive conflict to describe this process in their research on children's understanding of temperature. In other research as well, there is a shift of attention away from extinction of the preconceptions to restructuring of these conceptions (Hewson, 1981; Posner, Strike, Hewson, & Gerzog, 1982; Strike and Posner, 1992; Jensen & Finley, 1995). Strike and Posner (1992) point out that the early work in conceptual change did not recognize the importance of the interactions between prior conceptions and the new conceptions. They note that conflict may actually occur through criticism of an old schema or conception, calling into question an old model, or disharmony between two conceptions: an old and a new conception, an old conception and a new observation, or an old conception and an old observation. Thus, the concept of 'conflict' was widening and was not limited to discrepant events.

In whatever way 'conflict' occurs, it leads one to be more or less dissatisfied with one's current model, to mistrust the model to some degree, or to discount the plausibility of the initial model (Duit, 1994; Scott, et. al.,

1991). Scott, Asoko, and Driver include in this category Cosgrove and Osborne's Generative Learning Model (1985) and Champagne, Gunstone, & Klopfer's (1985) Ideational Confrontation Model. In both models conflict is induced between the student and the teacher or between the student and other students, as well as through the introduction of discrepant events. Duit, on the other hand, speaks of continuous and discontinuous pathways. He contends that it is only in discontinuous pathways, in which fundamental restructuring occurs in the preconceptions of the student, that conflict occurs.

Major restructuring that requires changing the ontological category of a conception has been found to be a much more difficult undertaking than simple change within an ontological category (Chi et al., 1994). The authors define an ontological attribute as a property that an entity may potentially possess as a consequence of belonging to that category (Chi et al., 1993). In their Incompatibility Hypothesis, the authors contend that when concepts do not require a major shift in ontological category, however, deep understanding may occur without similar difficulty.

Some researchers, however, advocate against initiating conflict at all and encourage introduction of a scientific model as another "way of knowing". Stavy (1991) used such an approach in her study on conservation of matter. She suggests that conflict may actually result in loss of self confidence and regression in students. Constructing a scientific model not intended to replace the current preconception but to coexist with it has also been suggested (Niedderer, 1987; Stavy, 1991).

Stavy and other researchers have focused on the use of analogy to build on preconceptions the student already holds (Brown and Clement, 1989; Clement, Brown, & Zietsman, 1991; Gorsky & Finegold, 1994; Glynn, Doster, Nichols, & Hawkins, 1991; Mason, 1994). Analogy is generally defined as forming a representation for a less familiar concept by means of a more familiar idea or concept. Mason (1994) further describes the process of analogy as detecting the similarities between two systems and then transferring relevant information to a target (the less familiar concept). Conceptual change research has used analogy to introduce a new idea or provide a bridge between a source conception and a new idea (Brown and

Clement, 1989; Stavy, 1991; Gorsky & Finegold, 1994; Glynn, Doster, Nichols, & Hawkins, 1991; Mason, 1994). Source conceptions are viewed not as misconceptions but rather naive conceptions which can be built upon with the use of scaffolding and bridging, leading to a refinement of the source conception or construction of a new conception. Dupin & Johsua (1989) further define this refinement to distinguish it from mere accumulation of new information. They state, "it does not consist of accumulating new notions upon previous ones, but of a real unceasing reconstruction of the range of knowledge." These authors point out that analogies can be used to achieve conceptual change.

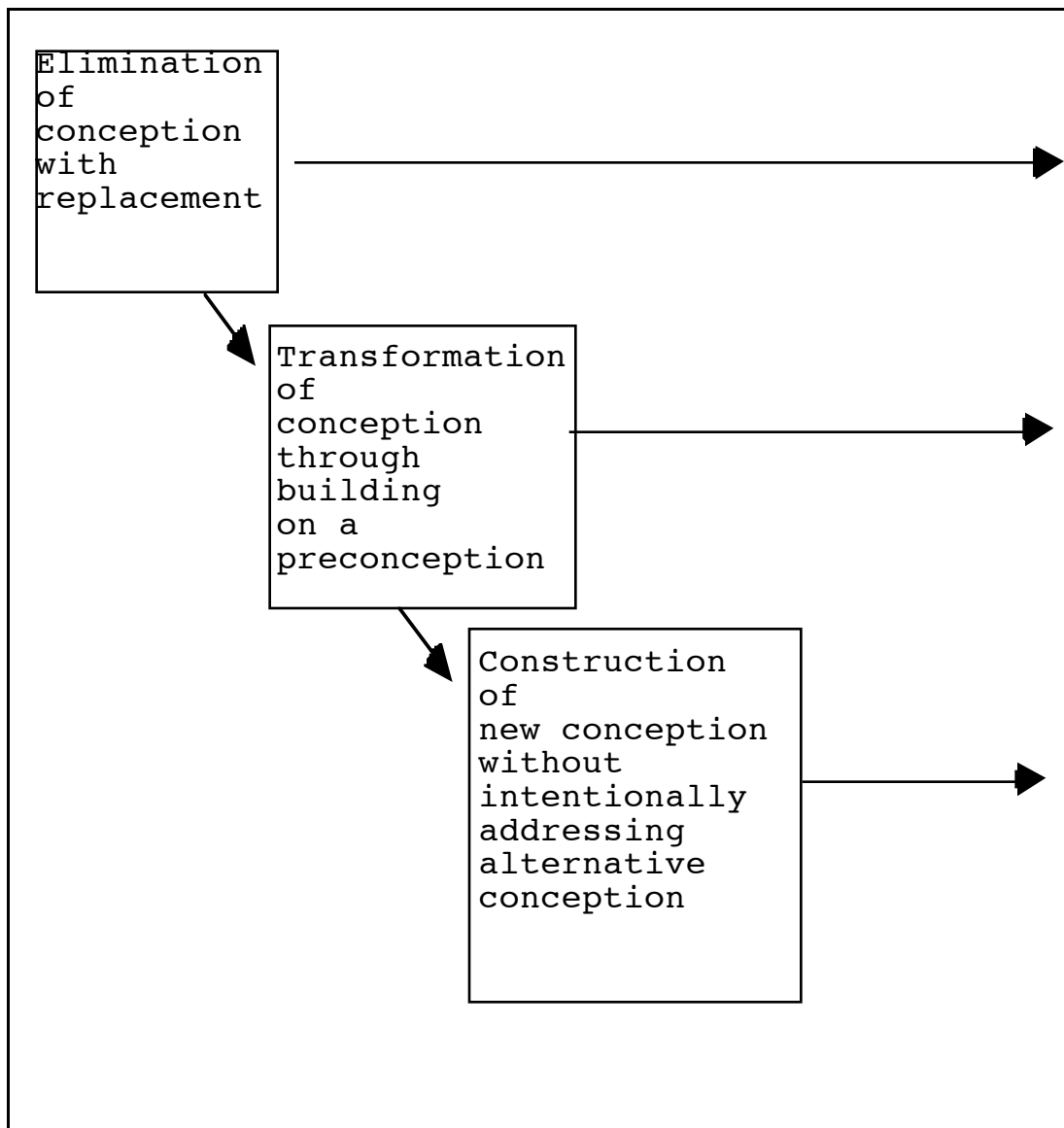


Figure I-1: Evolution of conceptual change theories

To summarize, the meaning of conflict has been modified over time to indicate those situations in which dissatisfaction with a preconception could lead to change without elimination of the old conception. However, some researchers advocate the avoidance of all conflict. It has been suggested that analogy may provide a means of achieving conceptual change without conflict. Figure 1 is our graphic representation of how this change in both strategies and terminology has evolved over the years. Researchers continue to disagree on how to achieve these changes. Some proponents favor the use of conflict to further conceptual change and others warn that it should be avoided. However, must all conflict be defined only in terms of major upheavals within the beliefs of an individual?

### TERMINOLOGY

As the strategies and sources proposed to initiate conceptual change evolved, the same terminology took on different meanings. This non-differentiation of terms leads to confusion. We suspect that disequilibrium can sometimes be based on dissatisfaction that is too mild to be called conflictual. In this paper we propose that there are milder forms of dissatisfaction in which a person feels an interesting sense of mild unease, and from which the person may experience a need to pursue some form of change. Therefore, we need a term for this unease, one that is not too harsh or too vague. For this reason, we propose two categories of unease formally referred to in the literature as conflict. We use the following definitions to distinguish between these categories:

1. Dissonance refers to a sensed internal discrepancy between a conception and another entity (observation or other conception).
  - a. Strong dissonance refers to an explicit, strong incompatibility between a conception and another entity.
  - b. Weak dissonance refers to a mild sensed discrepancy.
2. Discoordination refers to a sensed incompleteness of an explanation, outside the domain of dissonance (Inagaki & Hatano, 1986).

It is our belief that a broader notion of dissonance that includes both a and b above, may actually be implied by most models of conceptual change. In this paper we concern ourselves only with the second of these terms, dissonance.

### **THE QUESTION OF DISSONANCE**

In the area of conceptual change, while the teacher or researcher may hope that the reaction to dissonance will be in the direction of change toward a more scientifically acceptable model, this may not always be the case. As shown by Chinn and Brewer (1994), students often have great resilience to dissonance and choose to ignore or discount the source of the dissonance in favor of the already existing preconception. In addition, there may be a form of dissonance that motivates change but that does not cause extreme discord between a prior conception and a new ideas. While the term conflict appears to indicate that the student is both aware that a discrepancy exists between their alternative conception and another conception, opinion, or observation, we suggest that the term dissonance indicates something that may begin as a more implicit disquiet that can stimulate a need for action.

Berlyn (1965) believed that an optimal degree of cognitive dissonance leads to curiosity and learning. In this paper we wish to examine the possibility that the nature of change from an initial preconception may often preclude the avoidance of dissonance -- that even when the teacher does not consciously seek to foster dissonance, the mere exposure to different ways of knowing may cause some dissonance. Historically, people have referred to the dissonance as "conflict" but with a broader definition of dissonance we can possibly envision other instances where dissonance exists without harsh confrontation.

#### **Dissonance vs. Outcomes of Conceptual Change**

Historically, people have thought of 'conflict' as the strongest form of dissonance. The terms conflict and dissonance are sometimes assumed to imply an approach to conceptual change that involves eliminating or replacing an existing conception. It is important, however, to differentiate dissonance itself from the transition process or outcome of conceptual change. In conceptual change situations starting from a prior model (P.M.),

M1, we hypothesize that at least four possible processes can occur (see figure 2). These include 1) discarding or eliminating the P.M. and replacing it with a new conception, 2) constructing a new model without change to the initial model, (M1 might continue to be used in practical contexts, with M2 being used in academic contexts), 3) modifying the P.M. through a transformation , and 4) constructing M2 via a change in a "copy" of M1, but the original M1 is retained for use in practical contexts. In Figure 2, 'substitution' refers strictly to an outcome where M2 now exists without M1, without saying whether that occurred via elimination or transformation. ('Replacement' on the other hand usually has a compound meaning in the literature implying both elimination and substitution).

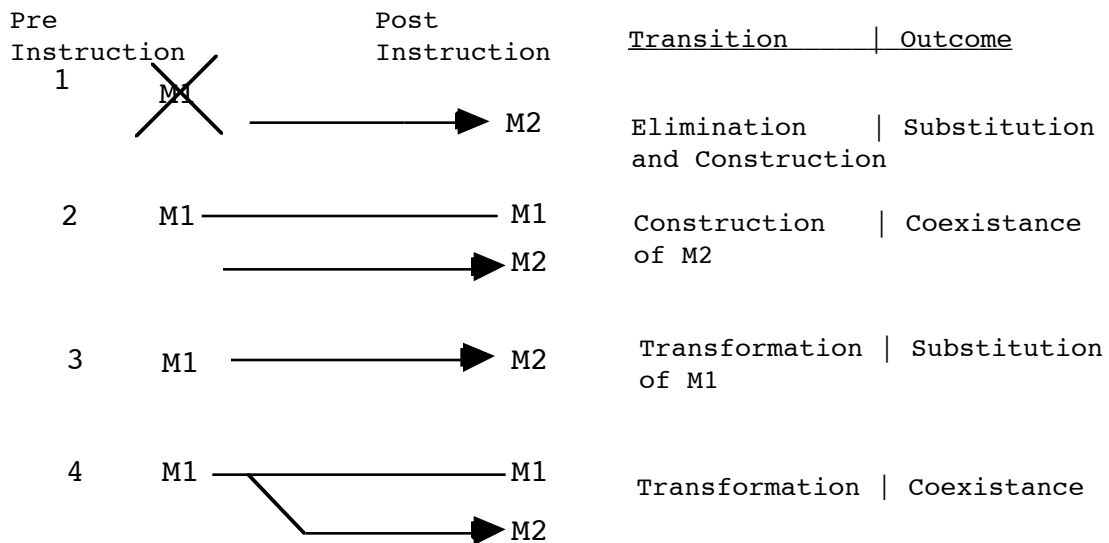


Figure I-2: Some possible transition processes and outcomes of conceptual change from an existing conception or model, M1

Hypothetical examples of each of the four processes and outcomes help to clarify our notations. An example of Figure I-2 (1) is the alternative conceptions that students hold about the effect of a vacuum on weight. Students are confronted with a bell jar with an object inside sitting on a scale. They are then asked whether the reading will change a large amount when the air is evacuated from the bell jar. Many students believe that the reading will be significantly less indicating that weight depends on downward air pressure. This prior model may represent an alternative conception that is

quite difficult to build on and the student may be best served by recognizing that it is not plausible and then building a new conception. Most students are willing to reject this idea once they see the experiment performed.

Process (2) represents a situation in which a student holds a prior conception about a topic such as sucking through a straw that is different from that taught in school. The student then finds it necessary to construct a new M2 concerning pressure differences that he/she uses in school situations but does not agree to give up M1 for other everyday situations. In this case the student may still hold on to the belief that M1 sufficiently explains most situations but that M2 has some uses in other contexts.

Process (3) may be seen in the study of electric circuits in which many students have a prior model of a 'squirt can' battery. In this model, electric charge squirts out of either end of the battery. Through teaching strategies that employ the sources of dissonance suggested in this paper as well as other research, students may begin to transform this model into a new conceptual model that has the charge coming only out of one end -- retaining the squirting idea, but only applying it to one side of the battery. Gradually the student begins to construct a model that not only recognizes that charge comes from only one end of the battery but also that charge moves through the circuit and returns to the other battery terminal. This then, is a transformation of M1 to M2 where M1 is not strictly eliminated but slowly transformed.

Situation (4) represents a scenario in which the student has a prior model similar to that in Process (3). In this process the student undergoes a transformation of their prior model -- the squirt can battery -- developing a more complex model of electricity. However, the student still maintains the original model of a squirt can battery to explain everyday situations such as a battery that has 'run out'.

In all the situations presented as examples, dissonance between a prior conception and an new conception, or between a prior conception and a new observation, may produce an effect within the student. We suggest that dissonance can play an important potential role as a stimulus for change and

knowledge construction for any of these four outcomes. In case (3) dissonance could have motivated the transformation of M1, even though M1 is not eliminated. Also, in case (2) dissonance with M1 could still have motivated the construction of M2, without necessarily eliminating M1. The same is true for case number 4--transformation with coexistence. Conflict is often associated in the literature with elimination or replacement of existing conceptions. However for the above reasons, we feel that views that associate dissonance with elimination or replacement alone are too narrow.

### Sources of Dissonance

In the past, dissonance was often associated with discrepant events as the source of dissonance. Consistent with our suggested definitions, Table 1 lists a variety of other possible sources of dissonance. These include both (1) external sources and (2) internal sources in which the student may produce dissonance within themselves through exploration and reflection on their own knowledge. However, the external sources of dissonance need to be recognized by the student and internalized for conceptual change to occur.

Dissonance may arise from a theoretical or empirical source. Theoretical sources may originate either between students, within a student, or between the teacher's model and that of the student; whereas empirical sources include those observed by the student as in labs, demonstrations, discrepant events, or recalled examples from practical experience in daily life.

SOURCES OF DISSONANCE	
<u>THEORETICAL</u>	<u>EMPIRICAL</u>
Model Suggested by Teacher	Observation/ Discrepant Event
Incoherence between two conceptions	Recalled discrepant Exemplars
Student or Teacher Criticism of Conception	Described Counter Example

Table 1: Sources of dissonance

These sources are far more diverse than discrepant events alone. Champagne, Gunstone and Klopfer (1985) and Basili and Sanford (1991) refer to an approach in teaching that uses both internal and external criticism and refutation as Ideational Confrontation (Duit, 1994). In this model students struggle to analyze their understanding of a conception and then interacts with other students in an attempt to justify this understanding. Others have initiated dissonance through open-ended questions (Dreyfus, Jungwirth, & Elkiovitch, 1990; Niedderer, 1987; Hewson & Hennessey, 1991; and Posner, Strike, Hewson, and Gertzog, 1982) and through experimentation and observation of labs, demonstrations, and teacher models (Niedderer, 1987; Stavy & Berkovitz, 1980; Stavy, 1991; Carey, 1989; Osborne & Wittrock, 1983; Scott, 1991; Rowell & Dawson, 1985). Jensen and Finley (1995) used historical arguments to induce cognitive dissonance for conceptual change. It may be that the use of analogy can also be a source of dissonance. Clement (1993) reported that bridging analogies had been observed to spark interesting arguments in large group discussions. Attempts by the student to reconcile a bridging analogy for an alternative conception that is also an analogy for a target conception could possibly lead to optimal dissonance -- that is, just enough dissonance to initiate or encourage change without undue distress.

External sources of dissonance, while recognizably dissonant from the teacher's view, may not be seen as dissonant by the student (Duit, 1995). That is, having a deeper understanding of a concept may allow the teacher to realize a conflict between the student's conceptual model and the scientifically accepted model. The teacher then sets up a situation in which this contrast is openly drawn. However, the students may find that their conceptual model satisfactorily explains events and relationships in the real world for them, and consequently the students do not recognize the need for another model. Attempts at introduction of external sources of dissonance may then be ignored or simply not recognized by the students. The students do not recognize dissonance since they see no reason to integrate or even entertain other information. Therefore, promotion of dissonance through external means may not always be effective in inducing change or growth unless the source of the dissonance is internalized. The conditions under which potential sources of dissonance actually produce internal dissonance are an important topic for future research.

Nevertheless, the successful use of dissonance produced by a variety of sources for promoting conceptual change has been documented in a variety of learning situations. Depending on how they are handled in the classroom, none of the sources in Table 1 need necessarily be confrontational, with the possible exception of student or teacher criticism of a conception. Often the problem is just the opposite--the student fails to see a difficulty with the conception even in light of the new source of dissonance. Thus there are many sources of dissonance that are not confrontational.

In summary, we have tried to separate potential sources of dissonance (Table 1) from an actual state of internal dissonance itself, and from the outcomes of dissonance in the form of conceptual change (Figure I-2). The sources of dissonance may arise internally, within the student, or externally, such as between other students and/or the teacher, or from observation. These sources do not necessarily need to involve harsh confrontation; thoughtful consideration of a discrepant event, analogy, counterexample, or alternative model may lead to curiosity and growth rather than discouragement. The conditions under which this occurs is a very important area for future research.

Whether the ultimate outcome of dissonance is elimination, modification, or coexistence of two models, may depend more on the way dissonance is employed by the teacher and the student, but it is not necessarily the case that dissonance must lead to elimination of an existing conception to be effective.

## CONCLUSION

There may be some in science education who continue to look skeptically at conceptual change strategies because they still associate the term conflict with elimination or replacement only. However, views that equate dissonance with replacement alone may be too narrow. Additionally, it is not the case that all teaching strategies that use dissonance are aimed at the eventual eradication of most of the student's preconceptions. In fact, since the outcomes of dissonance vary, (see Figure I-2) dissonance should not necessarily be equated with elimination or harsh didactic

confrontation. Certain carefully chosen discrepant events may actually be sources of just enough dissonance to encourage change; and this need not require the complete elimination of a prior model.

Dissonance itself may take the form of a disquiet or uneasiness before the student even recognizes the discrepancy between his/her own model and the target model. It may arise as an internal disquiet which propels students to question or criticize their model or it may be directly initiated from external events which cause a range of reactions from mild curiosity or surprise to cognitive conflict. Dissonance does not just arise from discrepant events; it may also arise from analogies, competing models, and recalled examples, and these may originate internally within the same student, or externally from other students or sources of authority. There are many sources of dissonance, both internal and external, that may work together to cause conceptual change (see table 1); these include discrepant events, analogies, familiar exemplars, and criticisms, as well as internal reflection. Whatever the source, however, it may be this dissonance that causes the student to engage in some internal struggle, to seek consonance. This, in turn, may lead to conceptual change. Such dissonance has been observed in some successful approaches even where researchers have indicated a desire to avoid what they call "conflict".

It may be that dissonance is, to some extent, unavoidable in learning situations where a prior model exists and could provide a useful tool in promoting conceptual change when used with care. Therefore, it is important to look for optimal ways to use dissonance before dismissing it as a strategy. That is not to say that one discrepant event, bridging analogy, or other source of dissonance is always, or even usually, sufficient. In our opinion, not nearly enough empirical work has been done to reach conclusions about whether all forms of dissonance are helpful or harmful in general; nor has this been done for specific strategies such as discrepant events. It may be that multiple strategies are needed to provide the scaffolding necessary for conceptual change to occur and this also needs further empirical investigation. It is better, therefore, to keep an open mind at this point with respect to the value of dissonance, to look for new

strategies and examine old strategies in an empirical search for optimal means of conceptual change.

**About the authors:** John Clement has been engaged in research on learning in mathematics and science at the University of Massachusetts for the past 20 years. His current research is focused on methods for helping students form and use visualizable models in science. This research is enhanced by studies of mental models used by expert scientists during problem solving. He has published several books in this area as well as a large number of articles on reasoning and learning in science and math. His work has been funded continuously by the National Science foundation for the last 18 years. He has served on boards for the National Science foundation, National Science Teachers Association, and the National Science Board. In addition to his research, Dr. Clement is a Professor of Education in the area of math and science.

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