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Response to Contradiction: Conflict Resolution Strategies Used by Students in Solving Problems of Chemical Equilibrium

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The main objective of this investigation was to show that a novel problem of chemical equilibrium based on a closely related sequence of items can facilitate students' conceptual understanding. Students were presented a chemical reaction in equilibrium to which a reactant was added as an external effect. A series of three studies were designed. In Study 1, the sequence of items started with a major alternative conception, namely, "After the reaction has started, the rate of the forward reaction increases with time and that of the reverse reaction decreases, until equilibrium is reached." In Study 2, the major alternative conception was presented the last. In Study 3, instead of the sequence, only the following statement was presented: "Rate of the reverse reaction increases gradually." In all three studies students had to agree/disagree with the statements and provide justifications. Results obtained show that at least one group of students, in Study 1 used a contradictory response pattern based on the generation and resolution of a cognitive conflict, which facilitated conceptual understanding. In Studies 2 and 3 students did not experience a similar cognitive conflict. Given the complexity of conceptual change and students' resistance to alter their alternative conceptions (cf. hard core, Lakatos (1970) *Criticism and the Growth of Knowledge*, Cambridge University Press, Cambridge, UK, pp. 91–106), it is suggested that changes in students' responses may have undergone a Peripheral Theory Change (Chinn and Brewer (1993) *Review of Educational Research* 63: 1–49).

KEY WORDS: Cognitive conflict; conceptual change; alternative conceptions; chemical equilibrium.

INTRODUCTION

Chemical equilibrium is considered to be one of the most difficult topics in the general chemistry program and various studies have investigated student difficulties in the topic (Bannerjee and Power, 1991; Bergquist and Heikkinen, 1990; Camacho and Good, 1989; Gussarsky and Gorodetsky, 1988; Hackling and Garnett, 1985; Hameed *et al.*, 1993; Johnstone *et al.*, 1977; Maskill and Cachapuz, 1989; Niaz, 1995a, 1998; Quílez-Pardo and Solaz-Portolés, 1995; Stewart *et al.*, 1982; Tsaparlis *et al.*, 1998; Voska and Heikkinen, 2000; Wheeler and Kass, 1978). Niaz (1995b) has investigated student understanding of chemical equilibrium and found that one of the most significant alternative conception students hold is that, "After the reaction has started, the rate of the forward reaction increases with time and that of the reverse reaction decreases, until equilibrium is reached." Hackling and Garnett (1985) had also reported a similar finding. In a recent study Niaz (1998) has shown that this alternative conception offers considerable resistance to change and hence can be considered as part of students' "hard-core" of beliefs. The concept of hard-core of beliefs has been adapted in the science education literature primarily from Lakatos' differentiation between the hard-core (negative heuristic) and soft-core (positive heuristic) of scientific theories (Lakatos, 1970). Generally, scientists resist changes in the hard-core of their

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theoretical frameworks and do not abandon a theory on the basis of contradictory evidence alone. Furthermore, according to Lakatos (1970), "There is no falsification before the emergence of a better theory" (p. 119).

The relationship between the process of theory development by scientists and an individual's acquisition of knowledge has been recognized by philosophers of science, psychologists, and science educators (Carey, 1985; Chinn and Brewer, 1993; Duschl and Gitomer, 1991; Glasersfeld, 1989; Karmiloff-Smith and Inhelder, 1976; Kitchener, 1986, 1987; Piaget and Garcia, 1989). In the context of science education, Chinn and Brewer (1993) have suggested that students also resist changes in the hard-core of their conceptions. Often students protect their hard-core of conceptions by accepting changes in the soft-core, which has been referred to as "Peripheral Theory Change" by Chinn and Brewer (1993).

Epistemologically, this study considers students' alternative conceptions not as mere mistakes but as conceptions that compete with scientific theories (cf. Niaz, 1998; Strike and Posner, 1992). Burbules and Linn (1988) have emphasized how students' alternative conceptions if contradicted can be the source of conceptual change: "... how students incorporate contradictions with currently held ideas [alternative conceptions] offer promise for understanding conceptual change" (p. 67). Similarly, Mischel (1971) has pointed out that "The cognitive conflicts which the child himself engenders in trying to cope with his world, are then what motivates his cognitive development; they are his motives for *reconstructing his system of cognitive schemas* ..." (p. 332, emphasis added).

Research literature in science education has also emphasized the role of cognitive conflict in conceptual change (Hewson and Hewson, 1984; Hewson and Thorley, 1989; Niaz, 1995d; Posner *et al.*, 1982; Rowell and Dawson, 1985; Strike and Posner, 1992). Similarly, the role of cognitive conflict and its resolution in human development has also been recognized (Festinger, 1957; Piaget, 1980; Vygotsky, 1978). A cognitive conflict can be produced by various situations: (a) surprise produced by a result which contradicts a student's expectations resulting in the generation of a conflict (Glasersfeld, 1989); (b) experience of puzzlement, a feeling of uneasiness, a more or less conscious conflict or cognitive gap (Furth, 1981); and (c) disequilibria—that is, questions or felt lacunae that arise when the student attempts to apply existing schemas to a new situation (Mischel, 1971).

One of the items used by Niaz (1995b) to evaluate student understanding of chemical equilibrium is given as

Item 1: A certain amount of NO(g) and Cl_2(g) are introduced in a vessel and the temperature is maintained constant. After the equilibrium is reached a certain amount of NO(g) is introduced into the vessel. As a consequence it can be concluded that

$$2NO(g) + Cl_2(g) \Longleftrightarrow 2NOCl(g) \quad (\Delta H < 0)$$

Item 1a: Reverse reaction rate decreases.
Item 1b: Forward reaction rate increases instantaneously.
Item 1c: Initially the reverse reaction rate remains constant.
Item 1d: Reverse reaction rate increases gradually.

It is important to note that this was not a multiple choice question. Students were asked to respond to each of the four items and provide justifications. It was found that 15% of the students responded correctly by disagreeing with Item 1a. This shows that 85% (those who agreed) of the students held the alternative conception that the reverse reaction rate decreases. Furthermore, it was found that of the 12 students who responded to Item 1a correctly, 11 (92%) responded to Item 1b correctly, 10 (83%) responded to Item 1c correctly, and 9 (75%) responded to Item 1d correctly. These results show that those students who understand correctly that the rate of the reverse reaction also increases, have a better understanding of other aspects of chemical equilibrium. In a subsequent study designed to replicate Niaz (1995b), it was found that some of the students responded to Item 1d correctly without having answered to Item 1a correctly. In order to pursue this apparently contradictory result further, three new studies were conducted, whose results are presented in this paper.

The main objective of this paper is to analyze strategies used by students in solving a novel item (Items 1a, 1b, 1c, and 1d, presented earlier), that can facilitate conceptual change. In Study 1 the sequence of items were presented in the following order: 1a, 1b, 1c, 1d. In Study 2 the order was inverted, that is 1d, 1c, 1b, 1a. In Study 3 only Item 1d was presented. The rationale for the differences in the three studies is presented in the Method section.

METHOD

Study 1 is based on 151 freshman students (Ss), Study 2 on 30 Ss, and Study 3 on 27 Ss. Students in all three studies were enrolled in Chemistry II for science majors at the Universidad de Oriente (Venezuela). All Ss were familiarized with the format of Item 1 (presented in the Introduction section), by solving 2 similar problems during class. Item 1 was originally adapted from Hackling and Garnett (1985) by Niaz (1995b) and since then has been used in other studies (Niaz, 1995a, 1998).

Item 1 formed part of the regular evaluation (monthly exam) of the students, and they were encouraged to explain all answers in writing. Ss were given explicit instructions with respect to the fact that Item 1 was not a multiple-choice question and that they were supposed to respond to each part of the item and justify it. Ss in Study 1 were evaluated on Item 1 with the sequence 1a, 1b, 1c, and 1d. Ss in Study 2 were evaluated on Item 1 with the sequence 1d, 1c, 1b, and 1a. Ss in Study 3 were evaluated only on Item 1d. Comparison of the performance of the Ss in the three studies is crucial for obtaining evidence in support of strategies that lead to conceptual change.

If the order in which the items are presented facilitates conceptual change, Ss in Studies 1 and 2 should differ in their responses to Item 1d. Those who do 1d last are more capable of undergoing conceptual change, whereas those who do 1d first may not experience conceptual change. This of course is based on the assumption that most Ss do not go back and check their response on the previous items in the sequence. Comparison of Ss performance in Study 3 with Studies 1 and 2 will show that if there is no difference across the three studies on Item 1d, then it could provide evidence that conceptual change is not occurring. Results obtained are summarized in Table I.

Table I. Response Patterns Used by Students in Study 1 ($n = 151$), Study 2 ($n = 30$), and Study 3 ($n = 27$)

	Response patterns	Number of students		
No.	Items 1a, 1b, 1c, & 1d	Study 1	Study 2	Study 3
1.	All 4 correct	9 (6)	2 (7)	—
2.	Conflict resolution strategy (1a = incorrect, 1d = correct)	31 (21)	—	—
3.	Only 1b correct	33 (22)	7 (23)	—
	Only 1c correct	—	3 (10)	—
	Only 1d correct	—	—	2 (7)
4.	Ambiguous	13 (9)	2 (7)	—
5.	All 4 incorrect	65 (43)	16 (53)	—

Note. In Study 1, the sequence of items were presented in the following order: 1a, 1b, 1c, 1d; in Study 2, the equence of items were presented in the following order: 1d, 1c, 1b, 1a; in Study 3, only Item 1d was presented; figure in parenthees repreent percentages.

RESULTS AND DISCUSSION

Table I shows that in Study 1, 21% (31 out of 151) of the Ss responded incorrectly to Item 1a (i.e., Ss consider the reverse reaction rate to decrease—a major alternative conception) and yet responded correctly to Item 1d (i.e., reverse reaction rate increases gradually). How do we explain this contradictory response pattern? A major thesis of this paper is to suggest that as these Ss solve the closely related sequence of Items 1a, 1b, 1c, and 1d, they go through the process of generation and resolution of a cognitive conflict (Burbules and Linn, 1988; Mischel, 1971). Before we analyze this hypothesis any further it would be interesting to present some of the problem-solving strategies used by the Ss. The following five strategies were considered to be representative of the 31 Ss who responded with this response pattern in Study 1. Each strategy is reproduced verbatim from Ss answer sheets, with only small grammatical corrections to facilitate understanding.

Strategy 1: Increase in the Concentration of Products Makes Its Dissociation More Difficult ($n = 8$)

Item 1a: "Yes. Concentration of NO(g) increases, which increases the rate of the forward reaction, leading to the production of more NOCl(g), which makes its dissociation more difficult."

Item 1b: "Yes. Addition of NO(g) increases its concentration, which leads to an increase in the forward reaction rate."

Item 1c: "No. While the forward reaction rate starts decreasing the reverse reaction rate starts increasing."

Item 1d: "Yes. As the forward reaction rate starts decreasing gradually, the reverse reaction rate starts increasing gradually."

Discussion

This strategy shows a progressive change in Ss understanding, which can be summarized as follows: Increase in the concentration of NO (Item 1a) → Increase in the concentration of products (Item 1b) → On Item 1c, instead of accepting the plausibility of the reverse reaction rate being constant initially, these Ss asserted that the reverse reaction rate starts increasing, which contradicts their response on Item 1a. Finally, on Item 1d the reverse reaction rate is considered to increase. It is plausible to suggest that these Ss did not go back and revise their response to Item 1a.

Strategy 2: As Additional Reactants are Added, Only the Rate of the Reaction That Consumes It Will be Favored ($n = 6$)

Item 1a: "Yes. On adding more NO(g), the reaction that consumes it will be favored. This can be achieved by increasing the rate of the forward reaction, which automatically reduces the rate of reverse reaction."
Item 1b: "Yes. The moment additional NO(g) appears, it progressively increases the rate of the forward reaction till the equilibrium is established once again."
Item 1c: "Yes. Forward reaction rate will be favored till the additional amount of NO(g) has been consumed. It is only then that the forward and reverse reactions will be equal. In the meantime the reverse reaction rate remains constant."
Item 1d: "Yes. After the additional amount of NO(g) has been consumed, the system will be in equilibrium, and then the rates of the forward and reverse reactions will be the same. Hence the rate of the reverse reaction will have to increase progressively in order to be equal to that of the forward reaction."

Discussion

This strategy considered that on Item 1a, an increase in the rate of the forward reaction automatically leads to a decrease in rate of the reverse reaction. This seems to be a memorized algorithm and may even reflect the application of an epigrammatic version of Newton's third law of motion, namely, for every action there is an equal and opposite reaction (cf. Brown and Clement, 1987; Niaz, 1995a). Responses to Items 1b and 1c indicate that Ss recalled that even after having additional reactant, equilibrium will be established once again. Finally, on Item 1d this is stated clearly and leads to the correct response.

Strategy 3: An Increase in the Rate of the Forward Reaction Leads to a Decrease in the Rate of the Reverse Reaction ($n = 6$)

Item 1a: "Yes. As can be observed from the equation, rate of the forward reaction is favored, which leads to a decrease in the rate of the reverse reaction."
Item 1b: "Yes. Till the equilibrium is established once again."
Item 1c: "Yes. In the initial phase only the reactants participate, leading to the increase in the rate of the forward reaction. Thus the rate of the reverse reaction remains constant."
Item 1d: "When the reaction reaches total equilibrium, the rates of the forward and reverse reactions are equal—thus the rate of the reverse reaction must increase gradually."

Discussion

This strategy is quite similar to Strategy 2. The essential difference being that in Strategy 3 the decrease in the rate of reverse reaction (Item 1a) is attributed more directly to an increase in the rate of the forward reaction. Furthermore, the reference to "equilibrium being established once again" (Item 1b) and "initial phase" (Item 1c) shows that the Ss differentiate between the original state of equilibrium and the one that will be established after the changes due to the external effect.

Strategy 4: As the Rate of the Forward Reaction Increases That of the Reverse Reaction Decreases ($n = 6$)

Item 1a: "Yes. As the rate of the forward reaction increases that of the reverse reaction decreases."
Item 1b: "Yes. Due to an increase in the concentration of NO(g), the rate of the forward reaction increases instantaneously, thus producing a disequilibrium."
Item 1c: "No. Due to the addition of NO(g), the rate of the forward reaction increases, which leads to a change in the rate of the reverse reaction."
Item 1d: "Yes. If the system has to achieve the state of equilibrium again, it must counteract the increase in the rate of the forward reaction, which means that the rate of the reverse reaction must increase."

Discussion

The essential feature of this strategy is that it points out to a "disequilibrium" (Item 1b) in the rates of the forward and reverse reactions. Thus an increase in the rate of the reverse reaction is accepted in order to "counteract" (Item 1d) the increase in the rate of the forward reaction.

Strategy 5: Displacement of the Reaction Toward the Products Leads to a Decrease in the Rate of the Reverse Reaction ($n = 5$)

Item 1a: "Yes. Concentration of one of the reactants is being increased. As a consequence the reaction displaces towards the products and the rate of the reverse reaction decreases."

Item 1b: "Yes. On adding NO(g) the rate of the forward reaction increases, leading to the production of more NOCl(g), and the establishment of the equilibrium."

Item 1c: "No. As the rate of the forward reaction increases, that of the reverse reaction decreases automatically."

Item 1d: "Yes. When the rate of the forward reaction increases that of the reverse reaction decreases. But in order to establish equilibrium again, the rate of forward reaction must be equal to that of the reverse reaction. Consequently, the rate of the reverse reaction will increase gradually."

Discussion

The essential difference between this strategy and the previous ones is that even in Item 1c it maintains that the rate of the reverse decreases. Thus the change in understanding from Item 1c to 1d is more problematic. Even then it is interesting to observe that the Ss apparently did not go back and check the response to Item 1a.

General Discussion

All five Conflict Resolution Strategies (Study 1) show that these Ss while solving Item 1a, explicitly manifest/hold a major alternative conception, namely, rate of the reverse reaction decreases, which supports previous findings in the literature (Hackling and Garnett, 1985; Niaz, 1995b). While solving Item 1b, Ss in all five strategies reason more or less correctly, that the rate of the forward reaction would increase. Strategies used to solve Item 1c indicate that at least some of the Ss have a better understanding of the problem situation. Except for Ss using Strategy 5 (who still maintain that "reverse reaction decreases automatically"), other Strategies (1–4) do manifest a change/transition in students' thinking. These Ss now maintain (in contrast to their position in Item 1a) that the rate of the reverse reaction either remains constant (Strategies 2 and 3) or starts increasing/changes (Strategies 1 and 4). Finally, in Item 1d all five strategies respond correctly that the rate of the reverse reaction increases.

Interestingly, Ss using Strategies 2–5, explicitly refer to the fact that as the system has to attain the state of equilibrium again, the rate of the reverse reaction must increase in order to counteract the increase in the rate of the forward reaction. It can be argued that Ss using Conflict Resolution Strategies do not experience a conceptual change/transition but rather invoke a memorized algorithm, namely "in the state of equilibrium the rates of the forward and reverse reactions are equal." This line of argument can be countered on the grounds that why did the Ss not use the memorized algorithm while solving Item 1a. Interestingly, none of the Ss responded with a response pattern in which only Item 1a would have been correct. These results raise an important issue: Did the Ss become aware of the contradiction, and if they did why they did not revise their responses to Item 1? It is plausible to suggest that all or at least some of the nine Ss who responded with response pattern 1 (all four correct, Study 1) might have gone back and corrected their answer to Item 1a. Such Ss would have become aware of the contradiction. Thus, apparently it is the sequence of closely related probing items that force the Ss to grapple with their alternative conceptions. This shows that given the opportunity (solving the novel Item 1) Ss can alter their alternative conceptions. On the other hand, traditional textbook problems generally fail to provide such opportunities for conceptual change.

Results obtained in Study 2 (see Table I) corroborate those obtained in Study 1. In Study 2 the sequence of Items was inverted (1d, 1c, 1b, 1a) and hence the Ss did not have the opportunity of experiencing a conflict. Interestingly, none of the Ss responded with Response Pattern 2 (Conflict Resolution Strategy) or Response pattern 3 (Only 1d correct). These results also provide evidence for the reliability of the study.

Results obtained in Study 3 (see Table I) show that 2 (7%) of the Ss responded correctly (Response Pattern 3, Only 1d correct). It is important to note that in Study 3, 1d was the only item presented. It is plausible to suggest that these Ss used the experience gained in class when two problems with a format similar to that of Item 1 were discussed. At this stage it is important to observe that the percentage of Ss who responded with Response Pattern 1 (Studies 1 and 2) and Response Pattern 3 (Only 1d correct, Study 3) is about the same (6–7%). This shows that in all three studies, some Ss either went back to check their answers in response to the contradiction or gained sufficient experience to solve the problem correctly.

CONCLUSIONS AND EDUCATIONAL IMPLICATIONS

It is argued that the sequence of problems (1a, 1b, 1c, and 1d) used in this study facilitated, at least one group of students, to generate and resolve a cognitive conflict. The experience gained in solving the sequence of items and the knowledge that the system attains equilibrium again conduces the students to the conclusion that the forward and reverse reaction rates must be equal, which contradicts a major belief (alternative conception) of the students that the rate of the reverse reaction decreases. As compared to most of the other studies (cf. Chinn and Brewer, 1993, for a review), results reported here are fairly different and novel as the cognitive conflict was not induced from outside but instead generated by the Ss themselves. A review of the literature also provides support for conceptual change not driven by externally provided data (cf. Levin and Druyan, 1993; Levin *et al.*, 1990a,b).

In spite of the promise such strategies may hold for introducing conceptual change in the classroom, we want to voice a word of caution as, "The course of conceptual change is anything but smooth" (Burbules and Linn, 1988, p. 75). Furthermore, we do not rule out alternative interpretations of the data. Taking our cue from the history of science (Lakatos, 1970) we suggest that Ss using Conflict Resolution Strategies in this study do accept and explain the anomalous data but still may have preserved the central hypothesis (hard core) of their alternative conceptions. This coincides with what Chinn and Brewer (1993, pp. 10, 11) have referred to as Peripheral Theory Change:

> . . . another response to anomalous data is for the individual to make a relatively minor modification in his or her current theory. An individual who responds in this way clearly accepts the data but is unwilling to give up theory A and accept theory B.

The idea of Peripheral Theory Change in the context of this study is particularly useful. Just as scientists, students may not accept contradictory evidence in order to produce radical changes in their alternative conceptions. Nevertheless, they may be more receptive to minor (progressive) changes. It is plausible to suggest that the novel item used in this study facilitates the transfer of knowledge gained in one item to the other (progressive transitions). Progressive transitions in the context of this study refer to models constructed by students that facilitate different degrees of explanatory power to their conceptual understanding (Niaz, 1995c).

Finally, results obtained in this study have educational implications in the sense that problems generally found in textbooks do not assess the potential to which students are capable of making a conceptual change/progressive transition. These findings highlight the importance of including novel problems of the type presented in this study (Item 1), that make the possibility of conceptual change as part of normal classroom practice.

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