

TEACHING CHEMICAL EQUILIBRIUM THROUGH CONCEPTUAL CHANGE APPROACH: A SYNTHESIS AND ANALYSIS OF THE LITERATURE

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ABSTRACT– This paper presents a thorough literature review on conceptual change approaches used for teaching and learning chemical equilibrium. The aim was to determine the type of conceptual change interventions that is most likely to benefit students and teachers. We begin with a discussion on the theoretical perspectives on conceptual change and then address ontological and epistemological issues, and their implications for conceptual change model. We then present a synthesis and analysis of conceptual change studies in chemical equilibrium to back our claim on conceptual change model. In the analysis we identified the kinds of instructional techniques in each intervention and ranked the interventions according to the number of instructional techniques present, and also computed effect sizes of the interventions. Correlations between effect size of an intervention and the number of instructional techniques in the intervention was very strong ($r = 0.97$). We argue that the relationship between students' post-intervention performance and the type of intervention was mediated by metacognition, and that that multifariousness of conceptual change intervention was key to the development of more holistic metacognition which directly influenced students' posttest performance. Further implications for theoretical perspectives on conceptual change and conceptual change instruction are discussed.

Keywords: Conceptual change, Chemical equilibrium, Metacognition, Instructional techniques.

1. INTRODUCTION

Conceptual change research in science education dates back to the 1970s with a focus on exploring students' misconceptions on science concepts. Following the pioneering work of Posner, Strike, Hewson and Gertzog (1982), the focus of conceptual change research shifted to addressing students' misconceptions through conceptual change instruction. The teaching models developed immediately were based on cognitive conflict strategies (Scott, Asoko, & Driver, 1991) and a number of conceptual change studies have used this approach. Cognitive conflict strategies were based on Piaget's notion of assimilation and accommodation and involve eliciting students' preconceptions and challenging their misconceptions with anomalous data (Posner et al, 1982). Drawing examples from history of science, psychology and education, Chinn and Brewer (1993) argued that response to anomalous data may occur in seven ways: ignoring, rejecting, excluding, abeyance, reinterpreting, peripheral change and theory change, out which only theory change guaranteed complete conceptual change. Thus the chances of achieving conceptual change cognitive conflict resolution strategies were limited. Further, criticism of Posner et al. (1982) model of conceptual change (Strike & Posner, 1992) rendered the cognitive conflict strategy theoretically less effective. In response, a number of cognitive models of conceptual change were proposed (Chi & Roscoe, 2002; diSessa, 1993; Vosniadou, 1994). However, critics from the sociocultural perspective argued that conceptual change is not only an internal cognitive process but one that happens in broader situational, cultural, and educational contexts and is assisted by the use of the relevant cultural tools and artifacts (Ivarsson, Schoultz & Säljö, 2002). This leads to the interpretation of conceptual change from multiple perspective involving cognitive and affective aspects (Treagust & Duit, 2009). It has been observed however that actual science classroom practice is far from what conceptual change perspectives propose (Duit & Treagust, 2012), a situation which may be due to frustrations for lack of effect on students' learning (Wenning, 2008). Many of the difficulties found in the application of the conceptual change approach in the classroom were related to the complexity of factors intervening in the context of school learning which conceptual changes

models do not take into account (Limon, 2001). Indeed most of the theoretical models proposed to explain conceptual change focused mainly on the individual's cognitive processes, not taking into account other individual's characteristics, such as motivation, learning strategies, epistemological beliefs and attitudes. Emerging views on conceptual change consider metacognition as a potential mediator for improvement in conceptual change learning, arguing that improved metacognitive skills are essential for durable and transferable conceptual change learning (Georghiades, 2000; Gunstone, & Mitchel, 1998; Yuruk, Ozdemir, & Beeth, 2003).

One concept in chemistry that has been posing conceptualization difficulties is chemical equilibrium. One of the reasons for these difficulties is the complexity of the concept, which demands the understanding of a large number of subordinate concepts and also abstract in nature (Quilez, 2009). Students' attempt to understand this concept has resulted in construction of faulty mental models. Early research on learning chemical equilibrium has documented a number of students' misconceptions on chemical equilibrium, related to dynamism, reversibility and completeness of reaction. For instance, equilibrium is seen as oscillating like a pendulum, (Bergquist & Heikkinen, 1990); students lack of awareness of dynamic nature of chemically equilibrated state (Gorodetsky & Gussarasky, 1986); students associate chemical equilibrium with static balance (Maskil & Cachapuz, 1989); students believe that the forward reaction goes to completion before the reverse reaction starts (Wheeler & Kass, 1978). Other researchers have reported on difficulties beyond conceptualization which include the use of ineffective learning strategies (Furio, Calatayud, Barcenas, & Padilla, 2000; Kousathana & Tsaparlis, 2002)). Later research on learning chemical equilibrium has been concerned with promoting understanding through conceptual change instruction. The purpose of this review was to determine the underlying factor of interventions responsible for effective conceptual change in chemical equilibrium and discuss its implications for conceptual change instruction in chemical equilibrium.

2.1 Theoretical Perspectives on Conceptual Change

Since the middle of the 1970s research has shown that students have intuitive or naïve ideas about scientific phenomena, which have been labeled "misconceptions" in the literature. Since then, many efforts have focused on changing these ideas in ways that can lead students to a correct understanding of science concepts. In Posner, Strike, Hewson and Gertzog (1982) view, learning as conceptual change means a transition from an initial conception about a phenomena, C1, regarded as naïve theories or misconceptions or alternative conceptions to a final conception about the phenomena C2, consistent with scientifically accepted views. This model of conceptual change assumes that each child comes to school with misconceptions about natural phenomena that are well articulated and symbolically represented and perhaps held in high esteem as paradigms to a community of scientists in Kuhn's notion (Kuhn, 1970). These alternative conceptions need to be elicited, challenged by explaining or demonstrating contrary examples and corrected by providing a more general concept that the student will accept and assimilate. The aim of instruction is to guide students toward accepting scientific views and incorporating them in their cognitive schemes. Posner et al (1982) outline four conditions under which conceptual change will occur. (a) There must be dissatisfaction with current conceptions; (b) a new conception must be intelligible; (c) a new conception must appear initially plausible; and (d) a new conception should suggest the possibility of a fruitful research program. Strike and Posner (1992) revised Posner et al. (1982) notion of conceptual change. They stated that in order to describe learners' conceptual ecology several factors should be considered such as motives and goals as well as their instructional and social sources. Furthermore, Strike and Posner (1992) shifted the limits of the learner's conceptual ecology to include currents conceptions and misconceptions interacting with other components of the conceptual ecology. Moreover, they proposed a developmental and interactionist view of the conceptual ecology.

diSessa (2002) pointed out the limitations of conceptual change research and criticized it for lack of theoretical accountability concerning the nature of the mental entities involved in the process of conceptual change. diSessa (2002) proposed a conceptual ecology approach, arguing that conceptual change involves organization and re-organization of a large number of diverse kinds of knowledge in

the student's conceptual ecology, into complex systems. He identified two different kinds of mental entities that get organized and reorganized in the process of conceptual change as p-prims (phenomenological primitives) and coordination classes. diSessa (1993, p.112) offered the meaning of 'phenomenological' and primitive:

They are phenomenological in the sense that they often originate in nearly superficial interpretations of experienced reality. They are also phenomenological in the sense that, once established, p-prims constitute a rich vocabulary through which people remember and interpret their experience. They are ready schemata in terms of which one sees and explains the world. There are also two senses of primitiveness involved. P-prims are often self-explanatory and are used as if they needed no justification. But also, primitive is meant to imply that these objects are primitive elements of cognitive mechanism-nearly minimal memory elements, evoked as a whole, and they are perhaps as atomic and isolated mental structure as one can find.

diSessa (2002, p. 38) claimed p-prims constitute the bulk of intuitive physics, the precursor knowledge that gets reconstructed into schooled competence with Newtonian physics. diSessa and Sherin (1998) defined coordination class as a systematic collection of strategies for reading a certain type of information out from the world. diSessa and Sherin defined two structural components of a coordination class: the set of read out strategies which involves 'integration' and 'invariance'; and the causal net which are intuitive expectation of a cause or theories that lie behind observations. Integration is the ability to coordinate observations or aspects in a single situation in order to read the required information while invariance refers to the ability to read out the same information reliably in different situations (p. 1172). According to diSessa and Sherin (1998), the causal net of naïve students consists of p-prims and it is the locus of difficulty in learning concepts of school physics. Moreover, diSessa and Sherin proposed that both invariance and integration may pose difficulties in 'recruiting and reorganizing' prior causal net knowledge, adding that invariance may be extremely problematic because different p-primes are evoked in different situations.

Vosniadou (2002) argues that that naïve physics is neither a collection of unstructured knowledge elements nor a collection of stable misconceptions that need to be replaced, but rather a complex conceptual system that organizes children's perceptual experiences and information they receive from the culture into coherent explanatory frameworks that make it possible for them to function in the physical world. The process of learning science to Vosniadou is slow and gradual during which aspects of scientific information are added on to the initial explanatory framework destroying its coherence until it is restructured in ways that makes it consistent with currently accepted scientific views. Vosniadou (1994) distinguished between a naive framework theory of physics and specific theories. Naïve framework theory is built early in infancy and consists of certain fundamental ontological and epistemological presuppositions not available to conscious awareness and hypothesis testing, whereas specific theories describe the internal structure of the conceptual domain within which concepts are embedded. According to Vosniadou, conceptual change proceeds through the gradual modification of one's mental model of the physical world, achieved either through enrichment or through revision. Enrichment involves the addition of information to existing conceptual structures while revision may involve changes in individual beliefs or presuppositions or changes in the relational structure of a theory. Revision may happen at the level of the specific theory or at the level of the framework theory. Vosniadou considered revision at the level of the framework theory to be the most difficult type of conceptual change and the one most likely to cause misconceptions. Vosniadou and Ioannides (1998) identified two types of conceptual change: Spontaneous changes in which initial conceptual structures can change as a result of children's enriched observations in the cultural context, or because of other kinds of cultural learning (such as language learning); and instructionally-based changes which are products of science instruction which could result in synthetic mental models (misconception) or scientifically correct mental models. In order to explain the spontaneous or instruction-based kinds of conceptual changes they made the following assumptions: (a) knowledge acquisition is a gradual process during which existing knowledge structures are continuously enriched and/or restructured; (b)

students are not aware of the hypothetical nature of the presuppositions and beliefs that constrain their learning; (c) the explanatory frameworks novices use lack the systematicity and coherence of the theory of physics used by experts.

Chi and Roscoe (2002) also emphasizes that even if the nature of misconceptions and conceptual change have been discussed for several decades within different research contexts, the literature only offers a fuzzy picture of what exactly misconceptions are, what constitutes conceptual change, and why conceptual change is difficult. They suggested that misconceptions should be considered as ontological miscategorizations of concepts. From this perspective, conceptual change can be viewed as a simple shift of a concept across lateral categories. They argue that this process is difficult if students lack awareness of when a shift is necessary and/or lack an alternative category to shift into. Ivarsson, Shoultz and Säljö (2002) support a sociocultural view of conceptual change as an alternative to the cognitive view. They questioned the claim that children hold such mental models that are inconsistent with scientific models and argued that such mental models may be a product of the investigative methods used. The authors claim that cognition is the use of tools, so conceptual change involves the development of tool-using practices. Mayer (2002) compared and contrasted four perspectives of conceptual change - Vosniadou's synthetic meaning view, Chi and Roscoe's misconception repair view, diSessa's knowledge-in-pieces view, and Ivarsson, Schoultz, and Säljö's sociocultural view. The four perspectives were compared in terms of what changes during conceptual change, who changes, how the change occurs, where the change takes place, the role of prior knowledge, and whether there is research evidence. In conclusion, he proposed a reconciliation of alternative views of conceptual change in search of answers to the age long question of how best to intervene for learners to benefit most.

2.2 Epistemological Perspectives on Conceptual Change

Naïve knowledge structure coherence is usually viewed from two prominent but competing broad perspectives: (1) knowledge as theory perspectives and (2) knowledge as elements perspectives. Essentially naïve knowledge may most accurately be represented as a coherent unified framework of theory-like character (eg. Chi & Roscoe, 2002; Posner et al., 1982; Vosniadou, 1994) or considered as an ecology of quasi-independent elements (diSessa, 2002).

Ozdemir and Clark (2007) argue that these two perspectives imply different pathways for implementing conceptual change in the classroom. The cognitive conflict model (also conceptual conflict) assumes that naïve knowledge has a theory-like nature and possesses some degrees of explanations power (Posner et al., 1982; Strike & Posner, 1992). This model assumes that conceptual change occurs by making students' dissatisfied with their existing conceptions and then rendering the scientific conceptions intelligible, plausible, and fruitful (Hewson & Hewson, 1982; Posner et al., 1982). This model assumes that when conceptual change occurs, the new conception replaces the old conceptions. On the other hand Cognitive perturbation model assumes that conceptual change takes place in a specific direction when a cognitive scheme, instead of producing the expected result, leads to perturbation, and perturbation, in turn, to an accommodation that maintains or re-establishes equilibrium (von Glaserfeld, 1995). The cognitive perturbation model involves step-by- step learning of concepts based on the understanding that paths of conceptual change for different students or groups of students are idiosyncratic, diverse, and context sensitive (Li et al., 2006).

Following the lack of consensus between on the nature of naïve knowledge, research has begun evaluating the comparative effectiveness of the cognitive conflict and cognitive perturbation approaches to conceptual change. For example, Dega, Kriek and Mogese (2013) reported that conceptual change instruction modeled on cognitive perturbation principle was more effective in promoting understanding of concepts in electricity and magnetism than the one modeled on cognitive conflict principle. This result is however not surprising, given that the conflict resolution process in the cognitive conflict model has been flawed for being at odds with constructivism (Smith, diSessa & Roschelle, 1993). The cognitive conflict model assumes that new information is exchanged with the

existing knowledge after the student finds it to be intelligible, plausible and fruitful. This assumption limits the knowledge restructuring process to assimilation of information, suggesting direct presentation of new information by the instructor. This is against constructivists' epistemology which views knowledge as existing in people's heads and constructed based on experience (von Glassersfeld, 1995). Inducing cognitive conflict in conceptual change instructions is however essential, though not sufficient to cause conceptual change (Lee & Byun, 2012). We therefore suggest the incorporation of conflict induction in a conceptual change instruction if it could be beneficial.

The degree of conceptual change is determined by the type of knowledge processing activities that followed the conflict, that is whether deep processing or surface processing strategies were employed (Chan, Burtis & Bereiter, 1997). Engaging in deep processing requires high level of metacognitive reflection and control (Rickey & Stacy, 2000) and mature epistemological beliefs (Windschitl, 1997). Such reflection may cause recognition of discrepancy in the knowledge building process. The revision of cognitive operations can lead to rectification of the discrepancy resulting in conceptual change. This is the mechanism that underlies the cognitive perturbation model of conceptual change (Li, Law & Lui, 2006).

Epistemological beliefs are individually held theory-like structures (Stathopoulou & Vosniadou, 2007) not available to conscious awareness and hypothesis testing (Vosniadou & Ioannides, 1998). These epistemological beliefs underlie the knowledge building process and influence conceptual change positively or negatively depending on whether they are mature or immature beliefs (Windschitl, 1997). Cho, Lankford and Wescott (2011) reported that students' epistemological beliefs significantly correlated with their views on NOS and conceptual change. However, there was no significant relationship between NOS views and conceptual change. This suggest that the relationship between NOS and conceptual change is mediated by epistemological beliefs. Nevertheless, there is a direct link between epistemological beliefs and metacognitive awareness with mature epistemological beliefs associated with high metacognitive awareness (Güven & Belet, 2011; Jena & Ahmad, 2013). Moreover, there is evidence that training in metacognitive awareness has positive influence on students' NOS views (Abd-El-Khalick & Akerson, 2009; Çetinkaya & Çakıroğlu, 2013) as well as students' understanding of science concepts (Georghiades, 2006).

Thus, metacognition is key to improving students' epistemological beliefs, NOS views as well as conceptual understanding. Since metacognition is trainable (Georghiades, 2006; Kramarski, 2004; Mevarech & Kramarski, 2003; Özsoy & Ataman, 2009) a conceptual change model should consider as its main agenda the development of metacognitive awareness. However given the multidimensional nature of the construct and other contextual factors that influence learning and the complex relationship that exist among these factors (Limon, 2001), designing conceptual change learning environment that promotes improved metacognitive awareness is a difficult task. We propose that metacognitive awareness, and for that matter, conceptual understanding will improve to the extent that a variety of instructional techniques are implemented in the instructional process. In the next session we present an analysis of conceptual change studies in chemical equilibrium that illustrates this proposition.

2.3 Effectiveness of Conceptual Change Instruction on Students' Understanding of Chemical equilibrium

Investigations into teaching and learning of chemical equilibrium can be traced along two main lines of research: studies that use refutation texts with other instructional techniques and studies that combine small group discussions with other instructional techniques. Refutation text is a text structure that challenges readers' misconceptions (Tippett, 2010). Refutation text passages always contain two components: the statement of a commonly held misconception, and an explicit refutation of that misconception with an emphasis on the currently accepted scientific explanation. A third component, a signal or cue that alerts the reader to the possibility of another conception, may also be present. Canpolat, Pınarba, Bayrakçeken and Geban (2006) used refutation texts and demonstration to create

cognitive dissonance and analogies to help in the assimilation of scientific concepts. The study employed a pre-test/post-test quasi-experimental design. The controlled group received instruction through the traditional teacher-centred approach while the experimental group was instructed through the conceptual change approach. The treatment conditions involved a liquid transfer analogy illustrating how a reaction proceed from start to equilibrium, graphing of data obtained from the analogy, demonstrations of effect of changing equilibrium conditions, questions and answer session, discussion, use of diagnostic questions and explicitly drawing students attention to misconceptions. The results showed that the students in the experimental group performed significantly better compared to the control group. Önder (2006) used refutation text to elicit students' misconceptions and to create cognitive dissonance and demonstration and analogy to aid assimilation of new concepts in solution equilibrium for experimental group while the control group was instructed by lecture/discussion method. The students in the experimental group had opportunities to discuss their ideas in small groups before the scientifically accepted explanations were given. Analysis of posttest showed that students in the experimental group performed significantly better than those in the controlled group. Similarly, Özmen (2007) used refutation texts in remediating high school students' misconceptions concerning chemical equilibrium. A quasi-experimental design was used in the study. While the experimental group received a refutation text instruction, the control group received a traditional lecture method instruction. The refutation texts were based on a three step cognitive dissonance resolution strategy where students' misconceptions were first activated through elicitation questions, followed by a prediction phase, and then presentation of correct scientific explanations supported by examples. The results of the study indicated that the students in the experimental group showed significantly greater levels of achievement than the students in the control group. Moreover, in both groups the percentages of students' misconceptions decreased, however the experimental group did better than the control group. Atasoy, Akkus, and Kadayifci (2009) used Predict-Observe-Explain (POE) demonstration to elicit misconceptions and refutation texts to highlight misconceptions while analogies and concept maps were used to aid assimilation of new concepts. In this study, a pre-test/post-test quasi-experimental design was employed. The controlled group was instructed by the traditional lecture method while the experimental group was instructed by the conceptual change approach. Results showed that the conceptual change approach was statistically more effective than traditional instruction in terms of students' conceptual understanding.

Mills and Alexander (2013) defined small group teaching as "any teaching situation in which dialogue and collaboration within the group are integral to learning" (p.4). The discussion is usually conducted on a problem. The small group is a more personal situation; it provides opportunities for high level of interaction between teacher and students and among students. Such interaction can foster active student engagement and learning at a high conceptual level, and can help students to achieve a sense of independence and responsibility for their own learning (Kelly & Stafford, 1993). Small group discussion was used by Akkus, Kadayifci, Atasoy and Geban (2003) to promote understanding of chemical equilibrium. The study was a quasi-experiment. The control group received traditional instruction involving sessions utilizing lecture/discussion methods to teach concepts while the experimental group received instruction based on conceptual change within the context of small group discussion. The conceptual change approach consisted of a three-stage teaching: first, students in small groups made a prediction about a situation using their preconceptions from which their misconceptions were identified; second, the teacher fostered cognitive dissonance by providing possible answers which were misconception of the phenomenon in question and suggesting counter questions for students to consider in their group discussions. Next, the students were provided with the condition to test their preconceptions and note their misconceptions in the concept. Finally, an explanation of the scientifically correct concept in the context of prediction questions, with feedback on the prediction questions was given by teacher. Results indicated that the students who used the conceptual change principles-oriented instruction earned significantly higher scores than those taught by traditional instruction in terms of achievement related to chemical equilibrium concepts.

Bilgin (2006) employed a pre-test/posttest quasi-experimental design to investigate the effect of small group discussion on students understanding of chemical equilibrium. The treatment comprised a

sequence of activities as follows: first the instructor gave short lecture on topics related to chemical equilibrium concepts, then students were put into groups of four and handed a worksheet. Students were asked to answer questions individually then, two students in each group together discussed the questions and wrote their explanations on their worksheets. Finally, students discussed and shared their ideas with other group members, reached a consensus and wrote their explanations as a group. When groups completed their work for each question, the instructor asked some of the groups to explain their findings for the whole classroom. During the discussion period, the instructor helped students having difficulty in finding relationships among concepts by giving students simple clues, reminding them of related parts of the lecture and giving feedback about their possible misconceptions. In the control group, students were instructed with traditional lecture instruction. Results showed a statistically significant difference between the experimental and control groups' posttest mean scores in favor of the experimental group after treatment. Around the same period, Bilgin and Geban (2006) investigated the effect of cooperative learning based on conceptual change conditions students' understanding and achievement in chemical equilibrium. Initially chemical equilibrium problems (both conceptual and numerical) were handed to students as worksheets to solve individually, and then discuss their solutions in groups in order to arrive at shared ideas. Next, the teacher provided the scientifically accepted ideas and also gave feedback. The groups then performed the analogies in order to understand the scientific concepts fully and also recognize the mistakes they committed in the initial problem solving situation. Finally, students applied the scientific ideas in solving other problems. Students took three quizzes individually within the last three weeks after they completed their group study. The quizzes were scored, corrected and graded by the instructor and the students reviewed their quizzes after the correction. This helped students to see their in-group performances and progressions. The first three groups in rank of success were rewarded for their improvement according to their scores on the quizzes. The control group was instructed through the traditional lecture/discussion and worksheet study approach but did not take any quiz. Results revealed a very significant effect of the conceptual change intervention.

Another research tradition that has informed research into teaching and learning of chemical equilibrium is argumentation. An argument is an attempt to establish truth and commonly consists of a claim that may be justified by either observable evidence, warrants (that relate the data to the claim), backings (the premises of the warrant), or qualifiers (the limits of the claim) (Osborne, 2010). Kaya (2013) investigated the effect of argumentation on pre-service teachers' conceptual understanding of chemical equilibrium using a quasi-experiment design. The controlled group received instruction through the lecture method while the experimental group was instructed through argumentation activities. At the beginning of the argumentation activities, the students were asked to answer the questions either by justifying their answers or select one situation from given two ones and justify their answer. Then, the instructor started a whole-class discussion and the students shared their ideas by explaining what they wrote in the task. During whole-class discussion, the instructor gave feedback to the students about their arguments in terms of their quality. Analysis of data revealed that the argumentation intervention was more effective than traditional lecture in promoting students' understanding of chemical equilibrium.

3. ANALYSIS OF CONCEPTUAL CHANGE RESEARCH IN CHEMICAL EQUILIBRIUM

Articles on teaching and learning chemical equilibrium included in this review were located by conducting an electronic search of 13 databases including Google Scholar, JSTOR and Ebsco Host, and the internet. The key words combination entered were "chemical equilibrium and conceptual change." This resulted in retrieving nine articles. In addition, references of the articles that were retrieved were checked to determine which articles were relevant (Randolph, 2009). This process resulted in the identification of additional ten articles. In all a total of twenty articles were retrieved. The following inclusion criteria was used to select article for analysis: (1) the study used experimental or quasi-experimental design, (2) ANCOVA statistics was used to analysis data (3) effect size statistics was reported or information was available for computation of effect size. The reason for including only the studies that used experimental or quasi-experimental designs is that the use of comparison groups

minimizes threats to internal validity of results (Trochim, 2000). The reason for including only the studies that used ANCOVA as data analysis is that even if treatment and control groups do not differ significantly on the pre-test, they may be other unmeasured variable on which groups differ prior to the intervention that may confound the results (Field, 2005). Moreover, inclusion of pretest as covariate in ANCOVA permit a better evaluation of the intervention as it controls for any pre-existing difference between treatment and control groups. Following the criteria specified above, a total of seven articles were selected for analysis. The analysis was done by considering the different types instructional techniques used in a study, whether misconceptions were elicited prior to instruction or not and the effect size. Table 1 (see Appendix) shows the analysis.

3.1. Discussions

Looking at Table 1 it appears that studies that tend to produce large effect sizes also involved the elicitation of misconceptions prior to instruction but we did not base our analysis on the place of elicitation of misconceptions in the instructional sequence for two reasons: first, the number of studies in which elicitation of misconceptions was not done prior to instruction are only two; second, the effect sizes for the two studies in which misconceptions were not elicited prior to instruction differ, suggesting that other factors may be at play. The pattern of relationship that is very apparent is that as the number of intervention techniques used reduces, the effect size decreases. A Pearson correlation revealed a very strong positive relationship between the effect number of techniques per intervention and effect size ($r = .97$, $p = .000$) meaning number of intervention techniques accounted for 94% of the variance in effect size. This result suggests that each technique made a unique contribution to the variance explained by the intervention leading to a larger proportion of explained variance as the number of instructional techniques within the intervention increases.

The analysis of studies in chemical equilibrium shows that the more the instructional techniques in an intervention, the better the practical significance of the intervention. Each instructional technique accomplished particular objective(s) which is part of a broader purpose of the intervention. Analogies and demonstrations in an intervention promoted spontaneous conceptual change through enriched observation provided by these techniques (Vosniadou & Ioannides, 1998). The use of analogy and demonstration on different occasions in the instructional sequence helped students to focus on the specific aspects of the chemical equilibrium concept across multiple contexts (Özdemir & Clark, 2007). Each of these techniques highlighted an important aspect of the equilibrium concept which enabled students to easily see and differentiate between them, engage in conflict resolution and coherence building between ideas (Parnafes, 2007). Also demonstrations served as external source of motivation required for engagement with the learning material.

Refutation texts served as metacognition enhancement tool that creates awareness of the existence misconceptions and also encouraged metacognitive reflection which improved reading and text comprehension during problem solving (Karami & Hashemian, 2012; Martínez, 2011; Tavakoli, 2014). This behavior was transferred to word problem solving leading to improved understanding of problem and better performance. Group discussions encouraged students to engage in metacognitive co-regulation during conceptual the change learning. As students collaborate during group discussions, they expressed their ideas in public, defended them in the face of questions from peers, questioned others' ideas, and were forced to elaborate, clarify, and reorganize their own thinking processes (Borkowski, Chan & Muthukrishna, 2000). The collaborative environment provided by group discussion promoted the development of metacognitive regulation (Schraw, Crippen & Hartley, 2006).

Hand, Prain and Collins (1999) argued that students' attempts either to read text or construct text involves them in processes in which they have to engage their own understandings to construct meaning for the science topics they are studying. Therefore, encouraging students to read text and write is a way to encourage the negotiation of meaning and construction of knowledge. In Bilgn and Geban (2006) study, students took three quizzes in addition to worksheets, discussions and analogies. The process of reading, writing and reviewing that characterizes quiz writing offered three additional

learning episode for the development of students' metacognitive skills (Avci, 2014; Hand, Wallace & Yang, 2004). We hypothesize that metacognition mediated the relationship between number of instructional techniques and effect size. As metacognition is a multidimensional construct, each instructional technique within the intervention influenced specific component of this construct, resulting in a more improved metacognitive awareness. The development of a more complete metacognitive awareness, granted by employing multi-technique intervention also made the conceptual change learning more permanent – hallmarks of effective conceptual change learning (Georghiades, 2000).

Conceptual change theories have given a multiple perspective to the nature of naïve cognitive structures with regards to science concepts and the processes of conceptual change. Each perspective suggests a specific line of action in knowledge restructuring process. We subscribe to the view that high level conceptual change is a complex process that no single conceptual change theory could sufficiently account for as so many factors come to play during the process of conceptual change (Limon, 2001). The multiplicity of perspectives on conceptual change should be regarded as indicative of this complexity rather than contradictory views. Each perspective should be viewed as an account of a unique aspect of conceptual change necessary but not sufficient for addressing issues in conceptual change on a large scale. According to diSessa and Sherin (1998), the causal net of naïve students consists of p-prims and that poses difficulty in learning concepts of school science. Vosnaidou (1994) considered restructuring at the level of the framework theory to be the most difficult type of conceptual change to achieve. Thus, we believe diSessa's p-prims and Vosnaidou's framework theory account for different facets of difficulty posed by intuitive knowledge in the process of conceptual change. Furthermore, Vosnaidou's description of naïve framework theory as consisting of certain fundamental ontological and epistemological presuppositions not available to conscious awareness and hypothesis testing suggest a need for instruction take into account the development of metacognition (Vosniadou, 2003; Vosniadou, 2007) as well as nature of science understandings and the relationship between views on nature of science and conceptual change. Finally, Ivarsson, Shoultz and Säljö (2002) notion of conceptual change as the development of tool-using practices emphasizes the need for using appropriate visual aids in promoting conceptual change.

3.2 Conclusions

The review of research into promoting conceptual change in chemical equilibrium has revealed that different instructional techniques can be used to enhance students' understanding of concepts. Moreover, a combination of instructional techniques is likely to yield better results than a single technique. Furthermore, it is evident from the existence different theoretical perspectives that conceptual change is a complex process. Conceptual change is multifaceted, with each perspective forming a face of this process. Focusing on the development of metacognition will be a way to reconcile all these theoretical perspectives in promoting conceptual change. Future research in fostering students' understanding of chemical equilibrium should include measurement of students' metacognitive skills in order to confirm our proposal.

4. TABLES.

Table 1. Instructional techniques used by researchers in teaching experimental group chemical equilibrium and their effect sizes

Study	Instructional techniques	Number of instructional techniques	Was misconception elicited prior to instruction?	Effect size (Eta Square)
Bilgn & Geban (2006)	Analogy, worksheet, three quizzes, small group	6	Yes	0.97

	discussions			
Atasoy, Akkus & Kadayifci (2009)	Refutation texts, analogy, demonstration, concept map, whole-class discussions	5	Yes	0.59
Önder (2006).	Refutation texts, analogies, demonstrations, discussions	4	Yes	0.47
Canpolat, Pınarba,, Bayrakçeken, & Geban (2006)	Refutation texts, analogy, demonstration, whole-class discussions	4	Yes	0.44
Bilgin (2006)	Modelling, worksheet, small group discussions	3	No,	0.37
Kaya (2013)	Argumentation practice, worksheet	2	No	0.14
Akkus, Kadayifci, Atasoy, & Geban (2003)	Worksheet, small-group discussions	2	Yes	0.13

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