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Examining the Factors That Influence Students' Science Learning Processes and Their Learning Outcomes: 30 Years of Conceptual Change Research

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This study used content analysis to examine the most studied conceptual change factors that influence students' science learning processes and their learning outcomes. The reviewed research included empirical studies published since Posner et al. proposed their conceptual change model 30 years ago (from 1982 to 2011). One hundred sixteen SSCI journal and full text articles were sampled from the Education Resources Information Center database. "Conceptual change" in the title of the articles was used for screening the articles. The results showed that learning outcomes chiefly examined students' conceptual change and their science achievement. The most studied factors influencing conceptual change were associated with instruction and personal reasoning ability. As for instruction, multiple instructional methods were usually integrated in the research, and "conceptual conflict" and "cooperative learning" were found to be gaining the most attention. In addition, certain instructional methods were more frequently linked to specific science subjects. Educators require knowledge of conceptual change theories and strategies. Such information should be more readily available in order to develop teachers' pedagogical content knowledge and help them put it effectively into practice.

Keywords: conceptual change, conceptual ecology, content analysis, Education Resources Information Center (ERIC), learning factor, learning outcome

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State of the literature

- There is little consensus on "what conceptual change is" or on "what changes in conceptual change." Multiple definitions exist, and researchers working in the conceptual change field subscribe to and represent different perspectives.
- Several studies highlight the factors that influence students' understanding of science concepts, but the related research is not well developed.
- Instructional method is a key to promoting conceptual change, and degree of cognitive conflict is central to how people respond to anomalous data.

Contribution of this paper to the literature

- We found the most studied factors influencing on conceptual change was instruction and personal reasoning ability in the ERIC database.
- Multiple instructional methods were usually integrated in research, and "conceptual conflict" and "cooperative learning" were found to be the most important instructional methods for conceptual change. Cooperative learning and experiment were more likely to be used in physics and chemistry.
- Educators require knowledge of conceptual change theories and strategies. Such information should be more readily available in order to develop teachers' pedagogical content knowledge and help them effectively transfer this knowledge into school science practice.

It has been 30 years since Posner and his colleagues (Posner, Strike, Hewson, & Gertzog, 1982) proposed the idea about learning requiring for conceptual change. During this period, an increasing number of studies have investigated how and why conceptual change occurs and what the difficulties are in learning scientific concepts across different ages, genders, subjects, and countries. Researchers seem to have reached a consensus on the difficulties associated with conceptual change in school science learning. This raises the question of the extent to which this broad research agenda and emerging findings match what has been published in journals that seek to influence classroom practice and guide science teacher instruction.

In an analytical study of citations from 365 identified journal articles on conceptual change (The articles were from the following publications: International Journal of Science Education, International Journal of Science and Mathematics Education, Journal of Research in Science Teaching, Research in Science Education, and Science Education), Chiu, Lin, and Chou (2016) found that the top 25 most cited publications (see Appendix A) out of 17,919 citations mainly discussed theories of conceptual change and originally appeared in periodicals (e.g., Pintrich et al., 1993; Posner et al., 1982;), databases (e.g., Pfundt & Duit, 1994), books (e.g., Carey, 1985; Kuhn, 1962), or book chapters (e.g., Strike & Posner, 1992). Among the top 25 most cited publications, eight articles were considered empirical studies, and five out of the eight investigated students' misconceptions. The other three empirical pieces were directly related to conceptual change (see Appendix A). From among these three publications, only one (Vosniadou & Brewer, 1992) had the keywords of conceptual change in its title, which was the criterion for inclusion in the study. In the sections that follow, we discuss our analysis of citations of SSCI publications (Chiu, Lin, & Chou, 2016) and our analysis of documents available through the ERIC digital library in order to demonstrate the differences between the publication content that science teachers are commonly exposed to versus the publication content that education researchers are exposed to and the impact this differential experience has on classroom practices.

What Conceptual Change Is and What Changes in Conceptual Change?

Research on conceptual change has received a great amount of attention among researchers who are interested in understanding the definition, nature, scope, and mechanism of conceptual change. Various definitions of conceptual change have been developed and revised as the theories supported by solid empirical evidences in the field. For instance, Vosniadou (1994) considered conceptual change as dealing with theory restructuring, whereby children modify their intuitive and synthetic mental models to scientific models. Chi (2008) argued that learning is not about adding new knowledge or filling in incomplete knowledge; rather, learning is changing prior misconceived knowledge to correct knowledge via ontological shifts. DiSessa (1993, 2008) commented that young children do not have consistent knowledge structures and instead, held knowledge in pieces and later formed coordination classes for knowledge construction. Tiberghien (1994) commented that different forms of conceptual change refer to theory revision (e.g., change of paradigms, principles, and laws), model modification (e.g., change of formalism, qualitative aspects), and changes in the experimental field of evidence (e.g., measurements, experimental facts). Caravita and Hallden (1994) reframed conceptual change from a contextual and situated perspective that moved the “cold” cognitive and individualistic view of much of the research on conceptual change to an analysis of contextual effects. This view was shared by Pintrich, Marx, and Boyle (1993) and Sinatra and Pintrich (2003). The studies on conceptual change have suffered from inexplicitness and imprecision in terms of what constitutes a concept and what changes in conceptual change (diSessa & Sherin, 1998). Taber (2011) criticized that even though two international handbooks on conceptual change have been published, there remains little consensus on the meaning of conceptual change among researchers in this area. Researchers tend to identify the meaning of conceptual change from different approaches based upon their specific research interests.

For instance, some researchers investigated how conceptual change was related to students’ achievement while others (i.e., Eryilmaz, 2002) merely examined gains between preconceptions and scientific concepts and then claimed conceptual change occurred. Still others might investigate curricular designs or teaching strategies that might enhance students’ science understanding. In this review, we answer the questions of “what conceptual change is?” and “what changes in conceptual change?” with empirical evidence rather than individual purpose or preference.

Which Factors Influenced Students’ Conceptual Change?

Several studies point to factors that potentially affect students’ conceptions, but the related research has not been well developed (Taylor & Kowalski, 2004). The features in conceptual ecology proposed by Posner et al. (1982) are generally acknowledged as the most influential factors in students’ conceptual change. The features of a conceptual ecology include (a) anomalies, (b) analogies and metaphors, (c) epistemological commitments, (d) metaphysical beliefs and concepts, and (e) other knowledge (such as knowledge in other fields or competing concepts). After examining several lines of criticism, Strike and Posner (1992) claimed that the factors of motivation, goals, and institutional and social sources should to be reconsidered. From the perspective of conceptual ecology, constituent ideas, ontological categories, and epistemological beliefs are believed to greatly influence students’ interactions with new ideas and problems. This perspective implies that the design of instruction (e.g., using anomalies, analogies, and metaphors), the quality and the structure of students’ prior knowledge, students’ motivation, and social context are significant factors in students’ science learning. Among them, instruction covers the most parts of conceptual ecology; therefore, it was the main factor that this review examined in depth.

In addition, although gender, grade, and reasoning ability are not elements of conceptual ecology, they could possibly influence students’ conceptual change. The research on gender in science has compared males and females on personal epistemology, ability, motivation, and interest in order to examine cultural and developmental explanations of documented differences (Kahle & Meece, 1994; Mason, Boldrin, & Zurlo, 2006). Kahle and Meece (1994) further pointed out that gender related differences in science achievement are trivial in primary school, but they increase as students proceed through the grade levels. In addition, as family and culture shape gender relationships in the primary and middle grades, the physical sciences and engineering are perceived as more masculine by male and female students. Mason et al. (2006) also suggested that gender and grade level significantly influence students' epistemology. Overall, boys show more absolutist positions than girls and the lower graders more than the higher graders. Lawson and Thompson (1988) claimed that students' reasoning ability could help them become aware of scientific conceptions; therefore, when following instruction, formal operational students would hold significantly fewer misconceptions than their concrete operational peers.

The Factor Covering Most Parts of Conceptual Ecology: Instructional Method

Instructional method is one of the most important factors when it comes to conceptual change and is the principal concern for science teachers and educators alike when they address students' scientific conceptions through teaching (Beeth, 1998). Lee and Byun (2012) stated that a cognitive conflict is clearly one of the main factors influencing how people respond to anomalous data, as it creates a condition of dissatisfaction through which students seize the opportunity to affect conceptual change. Baser (2006) claimed that since the 1990s, cognitive conflict based instruction has been extensively used in science education. Although researchers generally acknowledge that the cognitive conflict method can increase student awareness of the limitations of their conceptual frameworks, this may not be enough to elicit conceptual change if the new conceptual framework to be acquired is too distant or difficult for students to understand (Jaakkola, Nurmi, & Veermans, 2011). According to this perspective, cognitive conflict is simply a "spark plug" of conceptual change, and therefore, it must be triggered at the beginning of teaching sequences that address scientific "misconceptions." Therefore, how to combine other instructional methods with cognitive conflict to enhance the effectiveness of conceptual change is one line of research for some science educators. Other researchers believe one of the main reasons for the relative failure of cognitive conflict is that too few students are able to reach a "meaningful" level of conflict. Following this line of thought, only students with enough "reasoning ability" can reach such a level (Limón, 2001).

In Kang, Scharmann, and Noh's (2004) study, logical thinking ability was found to be positively correlated with cognitive conflict. If students experience too low or too high a level of cognitive conflict, the conflict will negatively affect students' learning (Lee & Byun, 2012). The empirical evidence to date supports the conclusion that moderate uses of cognitive conflict are helpful in promoting conceptual change (Vosniadou, 2008). In response, some researchers have suggested gentler ways of obtaining conceptual change like, for example, through the combined use of analogies and moderate cognitive conflicts (Clement, 2008).

Accordingly, in this review, we report how many types of instructional methods for conceptual change are present in the journal articles. This review enables us to answer the following questions. How many studies adopted conceptual conflict method only? How many studies adopted conceptual conflict combined with other instructional methods? How do these studies combine these instructional methods to enhance the effectiveness of conceptual change?

Framework of This Study

This study includes two main sections. One section focuses on factors influencing conceptual change and the other focuses on students' learning outcomes. Based on the literature review described above, this study categorized factors of conceptual change into two types (Figure 1): instructional intervention and personal characteristics (i.e., grade, gender, reasoning, motivation/attitude, and social context and others). In addition to these factors, we also included teachers as one of the aspects investigated in this study because of their importance in science education (National Research Council, 2001). We further identified whether an intervention involved teachers. For instructional interventions with at least one teacher, we considered the research as "classroom instruction" (that included cognitive conflict, analogy, multimedia, models and modeling, and so on). The other instructional interventions without teacher involvement were categorized into two sub-categories: text design and digital learning.

Tippett (2010) argued that textbooks are the dominant source for science instruction in most classrooms; therefore, text design for facilitating conceptual change should be examined. His review of refutation text in science education indicated that reading refutation text rather than traditional expository text was more likely to result in conceptual change. As new technology emerged, except textbooks, digital leaning instrument is the other powerful tool for us to explore its design and effectiveness for assisting students' conceptual change. Furthermore, this review addresses what has been uncovered regarding specific instructional methods for specific school science subjects. As for learning outcomes, we created the categories of conceptual change, science achievement, attitude, both of conceptual change and science achievement, and others to examine how these factors

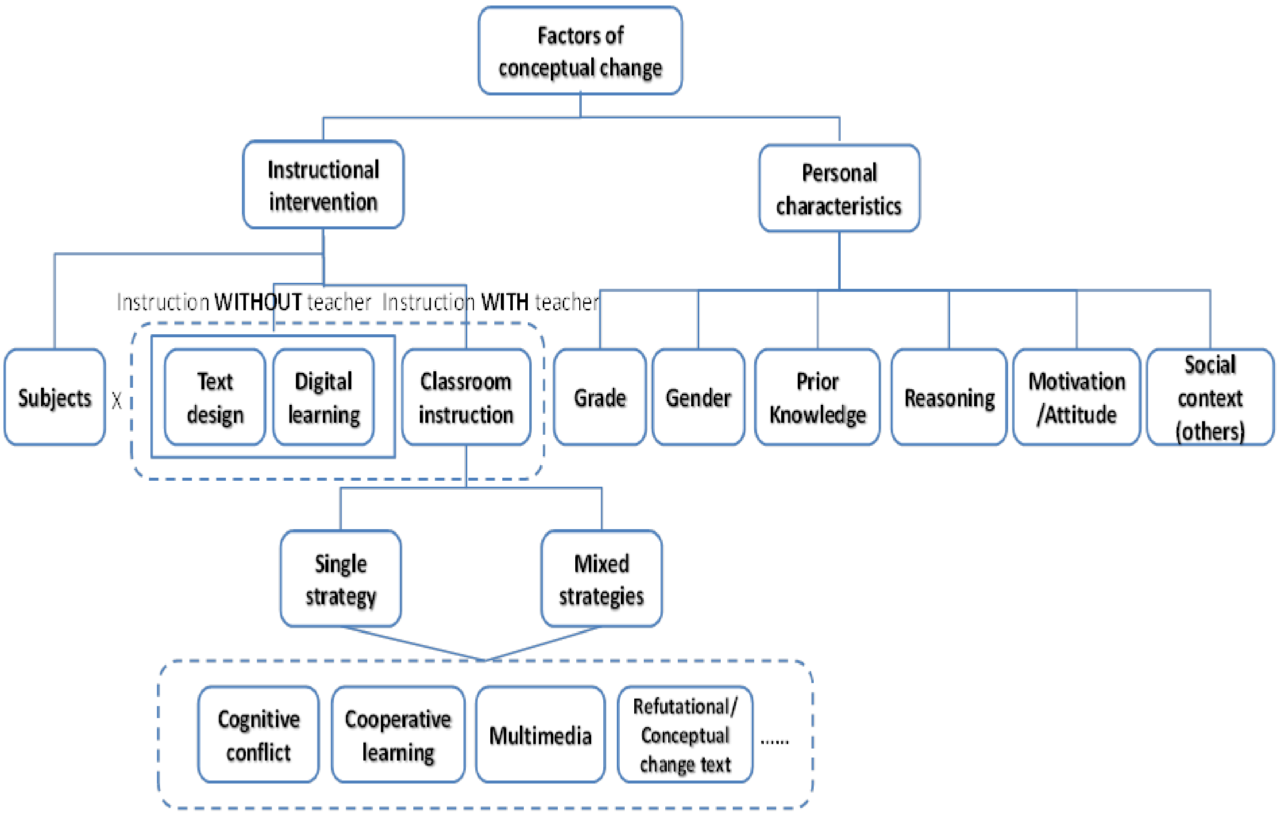

Figure 1. The framework of this study

influenced students' learning outcomes and how effective these factors were in producing conceptual change.

Taber (2011) commented that a strong synthesis of the current knowledge on conceptual change was often expected; however, "conceptual change" is still a contested and messy field of study that invites researchers to explore. Several questions remain unanswered. For instance, what has been completed in the area of conceptual change in relation to school science subjects? Which research methods have been used to uncover learning difficulties? Which characteristics of scientific concepts were challenging for students to learn? Which factors facilitated conceptual change? What were the instructional strategies commonly used in teaching and in what ways were alternative conceptions removed or modified (Taber, 2009)? These questions are strongly related to the practice of science education, and we drew conclusions from the empirical data in order to answer the questions listed above. More specifically, we conducted a content analysis to review select journal articles in the area of conceptual change in the Education Resources Information Center (ERIC) database. Aside from Google Scholar, the ERIC database is the primary educational resource for educators, practitioners, and the general public and allows free access to full-text articles (Howland, Howell, Wright, & Dickson, 2009). Although Google Scholar has superior search capability, it includes informal periodicals (e.g., magazines) and is spotty in locating materials published before 1990 (Howland et al., 2009). The specific research questions (RQs) were as follows:

1. What were the factors and learning outcomes in quantitative and qualitative conceptual change studies from 1982 to 2011?
2. What were the instructional methods used for specific science subjects in these studies during the same time period?

Method

Data Collection: Identifying Publications for This Review

To address the purposes of this study, this review used the ERIC database. This database is an online digital library of education research and information and provides a comprehensive, easy-to-use, searchable, Internet-based bibliographic as well as full-text database for educators, researchers, and the general public (Colker, 2000). For these reasons, the ERIC database was used to search for the desired papers on conceptual change with the criteria that the term "conceptual change" appear in the title during our 2012 online search. The time span was set at 1982 to 2011 to honor the first conceptual change model proposed by Posner et al. in 1982. The document type was limited to social sciences citation index (SSCI) journals and full-text articles directly from ERIC to ensure that the studies were of potentially higher quality and more broadly accessible to science education practitioners and the general public rather than just to science education researchers. This is in contrast to previous studies that focused solely on predetermined SSCI journals that are accessible only to researchers from specific academic fields (e.g., Lee, Wu, & Tsai, 2009; Tsai & Wen, 2005).

The abstract and title of each article were then read and screened by the 14 panel members, and an article was included in this review if it involved conceptual change in a science domain (not including mathematics). The above screening process yielded 116 empirical research articles (see Appendix B).

Data Analysis

Coding scheme. The 14 panel members each held a PhD degree in science education or education and applied the initial coding scheme to analyze 10 sample articles and then had three panel discussions and coding workshops to clarify and agree upon definitions of the codes. The panel members then used multi-stage coding to systematically analyze these articles. The first stage involved research type (i.e., quantitative or qualitative); the second stage involved the identification of the factors that influenced conceptual change: personal characteristics (i.e., gender, grade, prior knowledge, reasoning motivation/attitude and social context and others) and instructional intervention (i.e., classroom instruction, text design, and digital learning). The coding of the instructional intervention here outlined the significance of the teacher's role. In other words, the research interventions involving text and digital learning did not involve teacher participation. Following the factors of personal characteristics and instructional intervention, this study also analyzed what do these studies influence on the science learning (i.e., conceptual change, science achievement, attitude, both conceptual change and science achievement and others) and how their effectiveness or impacts are. If the authors stated their intervention was effective, the effectiveness code would be "Yes,"

Table 1. Coding scheme of the study

Category	Subcategory	Sample analyzed (n)
RQ 1 Factors and learning outcomes		Quantitative research articles (83)
RQ1-1-1 Factors in quantitative studies	1. Personal characteristics (1) Gender, (2) Grade, (3) Prior knowledge, 4) Reasoning (5) Motivation/ attitude, (6) Social context and others. 2. Instructional intervention (1) Classroom instruction, (2) Text design, (3) Digital learning	
RQ 1-1-2 Learning outcomes in the quantitative studies	1. Conceptual change, 2. Science achievement, 3. Attitude, 4. Both of conceptual change and science achievement, 5. Others.	
RQ 1-1-3 Effectiveness of the quantitative studies	1. Yes, 2. No	
RQ 1-2-1 Factors in qualitative research	1. Personal characteristics (1) Gender; (2) Grade; (3) Prior knowledge; 4) Reasoning (5) Motivation/ attitude, (6) Social context and others. 2. Instructional intervention (1) Classroom instruction; (2) Text design; (3) Digital learning.	Qualitative research articles (33)
RQ 1-2-2 Learning outcomes in the qualitative studies	1. Conceptual change; 2. Science achievement; 3. Attitude; 4. Both of conceptual change and science achievement; 5.Others	
RQ 1-2-3 Effectiveness of the qualitative studies	1. Yes; 2. No	
RQ 2 Instructional methods in the classroom		Articles related to classroom instruction (94)
RQ 2-1 Types	1. Conceptual conflict; 2. Multimedia; 3. Cooperative learning; 4. Refutational/conceptual change text; 5. Experiment; 6. Models and modeling (including analogy); 7. Inquiry (including problem solving, situational learning, contextualized learning); 8. History of science; 9. Others.	
RQ 2-2 Subjects and types	1. Physics; 2. Chemistry; 3. Biology; 4. Earth Science; 5. Other	

otherwise, the code would be "No." These steps allowed us to answer the first research question (RQ1).

We mainly valued the role of instructional intervention. It was the core of our second research question (RQ2). All articles with instructional interventions were analyzed on their related subjects (i.e., physics, chemistry, biology, earth science and others). Among the three identified instructional interventions (i.e., classroom instruction, text design, digital learning), we adopted the narrow definition of "classroom instruction" as comprising an instructional method. Then, we identified whether single or multiple teaching strategies were adopted in the classroom instruction, which was the most important sub-category of the instructional intervention. The final stage further divided teaching strategies into sub-categories of classroom instruction (i.e., conceptual conflict, multimedia, cooperative learning, refutational/conceptual change text, experiment, models and modeling/analogy, inquiry/problem solving/situational learning/contextualized learning, history of science, and others). The final version of the coding scheme is shown in Table 1.

Reliability. After three panel discussions and coding workshops, each study was independently analyzed and coded by at least two members of the panel. Once the independent analysis was completed, the two examiners met and compared their results. Disagreements among the two examiners were resolved by revisiting and discussing specific segments of the study together or by adding opinions of a third member if necessary. The data from the original research that was used to determine the code data for "factors and learning outcomes" (RQ1) and "instructional methods used for specific science subjects" (RQ2) were rechecked by the third author and the second author in this study respectively. After two months, they re-coded the data again. The internal consistency of the coding and re-coding for RQ1 and RQ2 was 89.7% and 88.9%, respectively.

RESEARCH RESULTS

RQ#1: Factors and Learning Outcomes

In the 116 empirical research articles, 83 of them collected quantitative data and the other 33 articles collected qualitative data. Table 2 and a detailed report of the factors and learning outcomes in these quantitative and qualitative studies follow.

RQ #1-1: Factors and learning outcomes in quantitative studies. Researchers have studied the effects of various types of variables to find their correlation to conceptual change. Table 2 shows the descriptive features of the factors (independent variables) and their learning outcomes (dependent variables) used by science education researchers in each study. The effectiveness of research results, on the other hand, is shown in the table to help justify the impact these intended factors had in influencing students' conceptual change. Table 2 shows that the personal characteristics studied the most were reasoning (10.8%), gender (8.4%), motivation/attitude (6.0%), grade (4.8%), and prior knowledge (4.8%). Some researchers might think a meaningful relationship exists between personal reasoning and science learning. For example, Alkhawaldeh and Olaimat (2010) tested whether reasoning ability and previous understanding of cellular respiration concepts made a statistically significant contribution to the variation in students' understanding of cellular respiration. Liao and She (2009) found that students with a higher level of scientific reasoning were better able to successfully change their alternative conceptions. As to gender-specific differences, Franke and Bogner (2011) found that young women retained the specialized scientific conceptions of molecular biology in the long term, whereas boys did only for a shorter period of time. The gender specific cross comparison between the two instructional groups showed significant differences on the posttest and delayed posttest of the boys, but not on those of the girls. Chambers and Andre (1997) investigated relationships between an individual's gender, attitude, and prior knowledge and conceptual change text interventions on learning electricity concepts. They found that prior interest level, experience, and knowledge mediated apparent gender differences in learning about electricity. Personal characteristics are comprised of a host of complex factors that are hard to study. Thus, few studies focused on clarifying the relationship between conceptual change performance and personal characteristics.

Science educators have designed interventions to help learners apply their new conceptions to solve problems or to facilitate further conceptual change. Table 2 shows that over 83.1% of the science education studies focused on the effects of classroom instruction, compared to 4.8% that focused on text design and 9.6% on digital learning. Interventions involving text design and digital learning allow students to only interact with the designed text or computers without teacher assistance. For example, the design of the text should support students in constructing a coherent mental representation. Students may become aware of their misconceptions and reflect independently on their own ideas by reading "conceptual change texts." In addition, some researchers tend to believe that the skillful use of hypermedia tools can foster conceptual change and the transfer of abstract scientific knowledge without teacher assistance. Most researchers tend to use a variety of strategies for science classroom teaching, rather than making students learn from texts and computers independently. In other words, most researchers emphasize the essential role of the teacher in the science learning process.

A variety of strategies for instruction intervention were identified, including learning cycle instruction, analogy activity, conceptual change strategies with conflict experiments, dynamic modeling, and so on. For instance, Yilmaz, Tekkaya and Sungur (2011) compared the effectiveness of learning cycle instruction and traditional instruction on eighth-grade students' understanding of basic concepts of genetics. Çalik, Ayas, and Coll (2009) investigated whether the use of an analogy activity enabled students to change alternative conceptions toward more scientific views for aspects of solution chemistry. In addition, Li, Law, and Lui (2006) found that dynamic modeling in conjunction with the use of a cognitive perturbation strategy by the teacher was effective in helping students migrate from their alternative conceptions toward a more scientifically inclined one. With regard to text design interventions, Beerenwinkel, Parchmann, and Gräsel (2011) designed a conceptual change text (criteria-based text) based on principles of text comprehensibility, conceptual change instruction, and instructional approaches to introduce the particle model. The results showed that reading the criteria-based text yielded improved results compared to reading a traditional text in learning the particle model. Muller, Sharma, and Reimann (2008) designed an interactive multimedia based on constructivism to allow students to build their own knowledge. Students on average were able to achieve higher posttest scores with interactive multimedia than with concise expository treatments. These studies focused on creating a self-constructed learning environment, such as incorporating cognitive conflict information in conceptual change text or making connections among macroscopic, microscopic, and symbolic levels of representation in animations, to foster individual learning.

Table 2. Number and percentage of quantitative and qualitative analyses on identified factors and learning outcomes

		Factor									Learning outcome							
		Personal characteristic						Instructional intervention										
		Gender	Grade	Prior knowledge	Reasoning	Motivation/ attitude	Others	Classroom instruction	Text design	Digital learning	Conceptual change	Science achievement	Attitude	Conceptual change + Science achievement	Conceptual change + Attitude	Conceptual change + Science achievement + Attitude	Others*	Effectiveness
Quantitative	Total	7	4	4	9	5	2	69	4	8	32	22	0	20	0	2	7	81
	%	8.4	4.8	4.8	10.8	6.0	2.4	83.1	4.8	9.6	38.6	26.5	0	24.1	0	2.4	8.4	97.6
Qualitative	Total	0	1	1	4	1	0	25	1	0	20	4	0	6	1	0	2	25
	%	0	3.0	3.0	12.1	3.0	0	75.8	3.0	0	60.6	12.1	0	18.2	3.0	0	6.1	75.8

Note: 1. Number of analyzed articles in quantitative research: 83; Number of analyzed articles in qualitative research: 33
2. *Others in the quantitative studies included 3 "conceptual change + science achievement + reasoning;" 1 "conceptual change + science achievement + belief; " 1 "conceptual change + reasoning;" 1 "conceptual change + knowledge"; 1 "conceptual change + metacognition."
Others in the qualitative studies included 1 metacognition; 1 online system sharing

In the analysis of the learning outcomes (dependent variables), because some studies examined more than two perspectives, the sum of the percentage in Table 2 is larger than 100%. Most researchers focused on observing and collecting students' conceptual change and science learning accomplishments. In Table 2, we can indeed see "conceptual change" (38.6%) as a dependent variable, and the other single variable is "science achievement" (26.5%). There was no study that only took "attitude" as a learning outcome, while 24.1% of the studies took both "conceptual change" and "science achievement" into account. For instance, when comparing the effectiveness of learning cycle instruction and traditional instruction on eighth-graders' understanding of basic concepts of genetics, Yilmaz et al. (2011) used a science achievement assessment consisting of 15 multiple-choice items, with one correct answer and three distracters, to assess eighth graders' understanding of basic terminology of genetics, Mendelian genetics, inheritance, and genetics crosses. Another example is the study conducted by Çalik et al. (2009). To determine if the analogy activity would be helpful in enhancing grade 9 students' conceptual understanding of solution chemistry, Çalik et al. used two concept test items, student self-assessment, and particularly, follow-up interviews with six selected students to launch an in-depth probe into students' understanding and in particular their reasoning.

Based on the analysis criteria set forth for the correlation between independent and dependent variables, "conceptual change" teaching interventions in 97.6% of the quantitative studies we reviewed were proved to be significantly effective in enhancing "science achievement." In other words, a good instructional design induces meaningful conceptual change and positive performance in science learning. Only in two studies did the designed conceptual change teaching intervention not achieve the expected results. For example, Windschitl and Andre's (1998) study showed no significant differences for treatment groups (the exploratory group vs. the confirmatory group) in some cardiovascular concepts. However, there was an interesting discovery that the level of epistemological sophistication and treatment interacted, in other words, the exploratory simulation environment was not necessarily appropriate for all students, only students with greater epistemological sophistication did better in this environment.

RQ #1-2: Factors and learning outcomes in qualitative studies. In order to promote students' conceptual change, a range of intervention strategies, focusing on the use of teaching methods or approaches, were devised. Through analyzing the assessments and results in the 33 qualitative articles, we identified the first factor, namely, the personal characteristics, including gender, grade, prior knowledge, reasoning, and attitude. Diakidoy, Vosniadou, and Hawks (1997) investigated whether different ages and cultural variables influenced the process of knowledge acquisition in astronomy. Twenty-six American Indian children in the first, third, and fifth grades were interviewed about the shape of the earth and the causes of the day/night cycle. The result showed that while the process of knowledge acquisition in astronomy followed a similar path for all children regardless of cultural variables, cultural cosmology influenced both the specific models constructed as well as the modes of explanation provided for astronomical phenomena. Liu (2004) checked whether students were motivated by computerized concept mapping that was intended to promote relational conceptual change. The basic social and affective requirement for concept mapping was to create a collaborative environment. For this purpose, students work in pairs or in small groups to construct concept maps so that negotiation of relations between partners or among group members may take place. The result showed that ongoing and collaborative computerized concept mapping (digraphs and digraphing) was able to account for student conceptual change in ontological, epistemological, and social/affective domains. Twigger et al. (1991) used computer software to develop students' reasoning and promote conceptual change in the mechanics domain and evaluated its effectiveness through analyzing results from interviews and classroom observations. The results showed that computer software was useful in exploring and developing students' reasoning and promoting conceptual change in this domain.

The second factor we identified was interventions, including classroom instruction, text design, and digital learning. Palmer (2003) focused on identifying the type of conceptual change (assimilation or accommodation) that could be induced by a refutational text. The results provide evidence that reading is a valid way of presenting science concepts to students and suggest that as long as students have an intention to learn, as well as appropriate epistemological beliefs, refutational text can induce accommodation in the majority of students. With regard to assessment, most researchers of the studies analyzed focused on investigating the process of conceptual change and science achievement, and the results showed that most of the studies yielded expected results.

Table 2 shows that a significant portion (12.1%) of the studies analyzed focused on the ability of "reasoning," with a mere 3.0% each for "grade," "prior knowledge," and "attitude." This tendency of overlooking personal characteristics in qualitative studies seems to mirror what we observed in the quantitative studies (i.e., 10.8% for "reasoning," 8.4% for "gender," 6.0% for "motivation/attitude," and 4.8% for "grade" and "prior knowledge"). However, it's apparent that reasoning, of all the personal characteristics, was the most emphasized for both the quantitative and qualitative studies. Table 2 also includes the factors comprising "instructional intervention" that were used in each qualitative study. As we can see, in order to promote conceptual change, "classroom instruction" was used most often (75.8%), "text design" was the second most often used intervention (3.0%), and "digital learning" was not used at all (0%).

Table 2 also shows that the most frequently used approach for assessment was "conceptual change" alone (60.6%), followed by using "conceptual change" and "science achievement" in combination (18.2%), and using "science achievement" alone (12.1%).

A very high percentage (75.8%) of the interventions were deemed effective. For example, through analyzing students' interview and think-aloud data, some studies found that most students were able to correctly describe the target concepts. Nearly one quarter of the studies showed that the intervention did not achieve the expected results. For instance, Tsaparlis and Papaphotis (2009) tested for deep understanding and critical thinking about basic quantum chemical concepts taught at 12th grade. The results showed the planetary Bohr model was strongly favored, while the probabilistic nature of the orbital concept was absent from many students' minds. This research approach to conceptual change employed active and cooperative forms of learning, which were consistent with social–cultural constructivism and with Vygotsky's zone of proximal development. Because mathematical descriptions and models were too difficult and complex for students to understand, these findings suggest that the uncertainty principle did not fall within Vygotsky's "zone of proximal development". Tabachnick and Zeichner (1999) tested how an action research seminar facilitated prospective teachers' learning on how to teach for conceptual change. The results showed most of the prospective teachers became experienced in eliciting students' prior knowledge. However, only a few teachers were able to use their knowledge of their students' thinking patterns to plan teaching activities because of the teachers' non-constructivist views of knowledge and their fragmented and static knowledge about science content.

RQ #2 Instructional Methods in the Classroom

This section reports on the results pertaining to the types of instructional methods implemented in the classroom and then illustrates the necessary combination of science subject(s) and instructional methods.

RQ #2-1: Types of instructional methods in the classroom. Among the 116 empirical studies, the effect of instruction on conceptual change was investigated in 107 articles. Instruction was not the focus in the other nine articles. While 94 of the 107 articles investigated conceptual change through classroom instruction, the other 13 articles did so by providing instructional materials alone (i.e., refutational text and digital learning) without teachers. Our second research question focused on the effect of classroom instruction analyzed in the 94 articles. Fifty-five studies used single instruction, while 39 studies used combined or mixed instructional methods. The number of articles in which one to four instructional methods were used was 55, 29, 9, and 1, respectively (Table 3). As is shown in Table 4, 144 methods in total were used across the 94 articles, and "conceptual conflict" was used most frequently (41 articles). It was used as a single method in 17 articles and used with other instructional methods in 24 articles. "Conceptual conflict" was frequently used with "cooperative learning" and "multimedia". It was also used with "models and modeling" and "experiment" in some studies. Following "conceptual conflict," the instructional methods of "cooperative learning," "multimedia," "refutational/conceptual change text," "experiment," "models and modeling (including analogy)," "inquiry (including problem solving, situational and contextualized learning)," and "history of science" were used with decreasing frequency. Most of the instructional methods were used in company with other instructional methods. "History of science" was always implemented with other methods, such as "conceptual conflict". Following "history of science," the ratio of multiple to single usages was higher than 3:1 for "cooperative learning," "multimedia," and "experiment." Besides combining with "conceptual conflict," "cooperative learning" was frequently combined with "multimedia" and "experiment." On the other hand, "refutational/conceptual change text" and "inquiry" were used alone or with other instructional methods equally often. In 18 articles, special instructional methods that couldn't fit into the above mentioned categories were used. They were common knowledge construction model, formative assessment, box and AVOW diagrams, cognitive apprenticeship, arguments/counter-arguments of the heuristic principles, data-based and explanation-based instruction, writing, tangible objects, status constructs, learning questions, learning cycles, concept mapping, classification training, and constructivist approach.

Some articles are briefly described next to illustrate a few effective instructional methods. For example, Hobson, Trundle, and Saçkes (2010) combined multimedia software, inquiry instruction, and collaborative learning for primary school students to learn the cause of moon phases. After the instruction, significantly more students understood the sequences and causes of lunar phases. In addition, the number of alternative conceptions held by students was reduced. Çalik et al. (2009) implemented their four-step constructivist teaching strategy in an analogy instruction on solution chemistry. Students' prior knowledge was first discussed and challenged. Then, an analogical map was used to reveal the like and unlike points between the source analog and the target conception. Yenilmez and Tekkaya (2006) demonstrated the effect of conceptual change text (or refutational text). In the text, students' misconceptions were elicited, the limit of their prior conceptions was revealed by presenting contradictory evidence, and the scientific explanation was discussed to make a distinction between the scientific and alternative conceptions.

Jensen and Finley (1995) taught evolution by presenting students with historical arguments among researchers. For example, Lamarck and Darwin's theories were compared and the evidences that Lamarck's principles couldn't explain were also presented. Keselman, Kaufman, Kramer, and Patel (2007) combined "critical reasoning" and "writing" activities to promote students' concept learning of real-life issues (i.e., HIV and AIDS). In the "critical reasoning" activity, students read a newspaper article about a yet unknown disease and discussed the impact of incomplete scientific knowledge on inducing misconceptions. In the "writing" activity, students pretended to be a counselor and had to respond to a girl who suspected that she got AIDS from her boyfriend. There were some misconceptions in the girl's letter, and the students had to rectify those misconceptions through writing to her.

Windschitl (1997) investigated the interaction pattern between pairs of students when they cooperated to learn photosynthetic and respiratory processes in plants via computer simulation. Students who had mature epistemological beliefs tended to ask more hypothetic and "what-if" questions, while students with immature epistemological beliefs tended to follow the instruction and responded to their partners passively. The post-test scores correlated positively with each student's

Table 3. Number of instructional methods used in each article

	Single	Multiple			Total
		Two	Three	Four	
Number of articles (%)	55 (58.5)	29 (30.9)	9 (9.6)	1 (1.1)	94 (100)
Subtotal	55		39		94

Table 4. Frequencies of each type of instructional method used with/without other instructional methods

Instructional method	Single	Multiple	Total
Conceptual conflict	17 (18.1)	24 (25.5)	41 (43.6)
Cooperative learning	4 (4.3)	17 (18.1)	21 (22.3)
Multimedia	2 (2.1)	12 (12.8)	14 (14.9)
Refutational/conceptual change text	7 (7.4)	7 (7.4)	14 (14.9)
Experiment	2 (2.1)	11 (11.7)	13 (13.8)
Models and modeling (including analogy)	4 (4.3)	7 (7.4)	11 (11.7)
Inquiry (including problem solving, situational learning, contextualized learning)	5 (5.3)	5 (5.3)	10 (10.6)
History of science	0 (0.0)	2 (2.1)	2 (2.1)
Others	14 (14.9)	4 (4.3)	18 (19.1)
Total	55	89	144

N = 94

Note: As is shown in Table 3, multiple methods were used in 39 articles. The number of methods used in conjunction with other methods totaled 89, and the total number of methods used (alone and with other methods) was 144.

Table 5. Science subjects instructed in each article with single/multiple instructional methods

	Physics *	Chemistry *	Biology	Earth science	Other	Not applicable	Total
Single *	17 (18.1)	19 (20.2)	15 (16.0)	2 (2.1)	3 (3.2)	1 (1.1)	57 (60.6)
Multiple	13 (13.8)	11 (11.7)	9 (9.6)	4 (4.3)	2 (2.1)	0 (0.0)	39 (41.5)
Total	30 (31.9)	30 (31.9)	24 (25.5)	6 (6.4)	5 (5.3)	1 (1.1)	96 (102.1)

N = 94

Note: * Double-coded. In two articles, both physics and chemistry were instructed with a single instructional method.

own epistemological beliefs but negatively with their partner's post-test score. It appeared that even if a student with low-epistemological beliefs was paired with a high-epistemological partner, that student did not ask similar questions as their partner, thereby resulting in a low post-test score.

RQ #2-2 Science subject(s) and instructional methods. Among the 94 articles, physics, chemistry, biology, and earth science were investigated in 30, 30, 24, and 6 articles, respectively (Table 5). There were two articles in which both physics and chemistry were taught. Five articles, in which "nature of science," "STEMS," "science and religion," "concept of learning and subsequent learning process" and "teaching" were instructed, were classified in the "Other" category. There was one additional article that did not reveal the instructional subject and was classified in the "NA" category. For physics, chemistry, and biology, a single instructional method was used more frequently than multiple methods. On the contrary, earth science was more likely to be instructed with multiple methods (but earth science was instructed in only six articles). As is shown in Table 6, "conceptual conflict" was again used most frequently for all subjects. "Refutational/conceptual text" was equally used in physics, chemistry, and biology classes. "Cooperative learning" and "experiment" were used more often in physics and chemistry classes. "Multimedia" was used slightly more often in chemistry and biology classes. "Models and modeling (including analogy)" was slightly more likely to be used in chemistry classes while "inquiry" was slightly more likely to be used in physics classes. However, "history of science" was only used in biology classes. From this review, it seems that some instructional methods were more frequently used for certain science subjects. This may indicate that certain instructional methods are more suitable for instructing certain subjects. For example, conducting experiments is almost impossible for teaching the origin of the earth, while modeling or simulation may be implemented more easily for the same subject matter. Although this review can be a guideline for the correspondence between instructional methods and science subjects, direct comparison or meta-analysis should be conducted to test the possibilities.

Table 6. Cross table for science subjects and types of instructional methods

Instructional method	P *	C *	B	ES	O	NA	Total
Conceptual conflict	18 (19.1)	12 (12.8)	7 (7.4)	3 (3.2)	1 (1.1)	0 (0.0)	41 (43.6)
Cooperative learning	7 (7.4)	8 (8.5)	3 (3.2)	0 (0.0)	2 (2.1)	1 (1.1)	21 (22.3)
Multimedia	2 (2.1)	5 (5.3)	4 (4.3)	3 (3.2)	0 (0.0)	0 (0.0)	14 (14.9)
Refutational/ conceptual change text	4 (4.3)	4 (4.3)	6 (6.4)	0(0.0)	0 (0.0)	0 (0.0)	14 (14.9)
Experiment *	5 (5.3)	6 (6.4)	3 (3.2)	0(0.0)	0 (0.0)	0 (0.0)	14 (14.9)
Models and modeling (including analogy)	2 (2.1)	4 (4.3)	2 (2.1)	2 (2.1)	1 (1.1)	0 (0.0)	11 (11.7)
Inquiry (including problem solving, situational learning, contextualized learning)	3 (3.2)	1 (1.1)	2 (2.1)	2 (2.1)	2 (2.1)	0 (0.0)	10 (10.6)
History of science	0 (0.0)	0 (0.0)	2 (2.1)	0 (0.0)	0 (0.0)	0 (0.0)	2 (2.1)
Others*	6 (6.4)	4 (4.3)	6 (6.4)	1 (1.1)	2 (2.1)	0 (0.0)	19 (20.2)
Total	47	44	35	11	8	1	146

N = 94

Note: * Double-coded. In two articles, both physics and chemistry were instructed with a single instructional method (experiment and other).

CONCLUSIONS AND IMPLICATIONS

This study used content analysis to examine the most studied conceptual change factors that influence students' science learning processes and their learning outcomes. The empirical research analyzed here was identified via the ERIC database. The ERIC database and the selection criteria used in this study were proper for addressing our specific research questions. Other studies using different databases and selection criteria have reported different findings, but their focus has been more on the world of academics (e.g., Lee et al., 2009; Tsai & Wen, 2005). The current study takes the practioners and the general public into consideration and includes these groups in its analysis in an effort to explain the real-world impact of the empirical research on conceptual change. The conclusions and implications of the content analysis are as follows:

Balancing Instructional Intervention and Personal Characteristics

Today, science education also focuses on learners' oral expression, translation of intrinsic values, and interpretation of classroom situations. As a matter of fact, qualitative studies have been gaining more attention in science education research, and recently many science education researchers have found that a majority of students hold alternative conceptions for many scientific concepts. The traditional ways of teaching have proven to be insufficient to alter these alternative concepts; that is why altering alternative concepts has become one of the imperative topics in science education.

The analysis of our data showed that qualitative studies of conceptual change still focused more on instructional interventions. In other words, these studies still focused more on the "original" conceptual ecology Posner et al. (1982) proposed. These studies elaborated more on how instructors should design their teaching models to improve learners' conceptual change, along with their interviews with students and classroom observations. These studies are nothing short of what mainstream contemporary quantitative or qualitative studies require, they, however, fall short in terms of addressing the effect of personal characteristics. If we compare the results with the outcomes we found in the quantitative studies, we see similar results leading us to believe we should focus more on teaching strategies for conceptual change; however, these studies also fall short in terms of providing insightful perspectives on the factors we believe affect learners' preconceived ideas, like learning materials, learning motives, prior concepts, and experiments commonly seen on science education study, etc. Epistemological and ontological views of conceptual change pertain to cognitive activities within students' minds, and they are mainstream theories derived from Posner et al. (1982) and Chi, Slotta, & de Leeuw (1994). Although Pintrich et al. (1993) argued that individual cognitive views of conceptual change ignore the mediating roles that affective, social, cultural, and environmental factors play in human cognition, few studies focused on exploring the effect of these overlooked factors. Some studies in our review observed gender differences in misconceptions. However, such differences were not manifested in the students' achievement scores. Although students' attitudes toward science make significant contributions to their variations in achievement, very few studies aimed to foster students' positive attitudes toward science.

Re-examining the Teachers' Role and Students' Epistemological Beliefs

As the value of an instructional intervention increases so does the importance of the science teacher. The fact that individual differences tend to be underestimated explains why in mainstream constructivism, personal characteristics are still being ignored. Most studies prefer designing a variety of strategies for science teaching over using a single strategy. For instance, teachers were encouraged to design dynamic modeling with the cognitive perturbation strategy (Li et al., 2006). After all, teachers cannot just let their students read the text without any teacher-student interaction in real situations. Similar problems happen in computer simulations, which offer opportunities for students to explore, but fail to challenge students' alternative conceptions. In other words, teachers need to provide cognitive perturbation at appropriate junctures in the inquiry process. In addition to instructional strategies, students' epistemological beliefs may have an influence on the depth of information processing and the potential for conceptual change. The importance of dissatisfaction with students' ideas for conceptual change was emphasized by some studies (Niaz, 1995; Thorley & Treagust, 1987). On the other hand, students were passive listeners in traditional instruction. Therefore, to help students reconstruct their own knowledge, teachers have to provide intelligible, plausible, and fruitful new concepts via daily life examples and encourage students to participate actively in classroom discussions.

Linking Instructional Methods and Subjects

To promote conceptual change, students need to know there are other competitive conceptions that may be more suitable for explaining a phenomenon. These competitive conceptions can be presented and contrasted through a variety of instructional methods. For example, conceptual conflict can be directly implemented in the classroom through multimedia, modeling, or refutational texts. The discrepancy may also be revealed through experiments and inquiries. In addition, by discussing with classmates or presenting historical accounts, students may discover some better-justified explanations. Thus, a variety of instructional methods and their combinations can be selected to promote conceptual change.

Bridging the Gap Between Research and Practice

As mentioned at the beginning of this article, an analytical examination of the citations in selected SSCI journal articles showed that most of the cited publications were related to the theoretical framework on conceptual change (Chiu, Lin, & Chou, 2016). However, this study analyzed another free educational database (ERIC) that was easily accessed by the general public. This study found that some internationally well-known and commonly cited articles reported in Chiu, Lin, & Chou (2016) were not included in the articles located through the ERIC database. This does not mean that the theoretical reports were not important to the field of conceptual change research. On the contrary, they should be included in ERIC so practitioners can access them and further enhance science educators' and our understanding of how to improve science teaching. We advocate that knowing instructional strategies is not enough to empower science teachers. The knowledge of underlying conceptual change strategies should be seriously considered for developing teachers' pedagogical content knowledge in practice. In addition, we recognize that there exist many other important and influential works that were not included in this study. The ERIC database, which is geared toward a more general user base, should consider expanding its scope in order to be of greater service to school teachers and other education professionals. Finally, we recognize the limitations of our data source and acknowledge the value of other more recently available sources such as Google Scholar, Scopus, and Web of Science that allow a wide range of readers to search for relevant citations for the purposes of research and practice in science education. When analyzing different data sources, it is important to be aware of how variation in their scope of coverage and search algorithm can generate different citation outcomes (Kulkarni, Aziz, Shams, & Busse, 2009). For example, a formal subscription may be required in order to use certain data banks (e.g., Scopus and Web of Science), and there is wide variability between data sources in terms of their availability of full texts (e.g., ERIC at 9% and Google Scholar at 39%; Howland et al., 2009). The present work demonstrates how analysis of the traditional and easily accessible ERIC digital library produced results very different from the analysis of SSCI journals as well as the Chiu et al. (2016) study that focused more on citations in the publications. Since each data source has advantages and disadvantages, it would be worthwhile to investigate how each contributes to our knowledge about conceptual change research and how to integrate various sources (traditional and more current databanks) in the future.

CONCLUDING REMARKS

In this review, more than one third (39 out of 94) of the studies adopted multiple instructional methods. Although "conceptual conflict" might be an important step to conceptual change, support from other instructional methods (such as "experiment," "modeling," and "multimedia") could deepen levels of dissatisfaction or make scientific conceptions more intelligible. In addition, "cooperative learning" was found to be popular in the review, presumably because our research question focused on classroom instruction and we selected articles from the ERIC database. This finding also supports the claim that social sources should be considered when it comes to instruction for conceptual change (Strike & Posner, 1992). Furthermore, "multimedia" and "refutational/conceptual change text" could be used with (in 14 and 14 studies) and without (in 8 and 5 studies) teachers. In some studies, the effect of multimedia or text was tested in a controlled laboratory environment. However, for practical reasons, using these instructional methods together with teachers and other methods might be more beneficial for students.

This review also revealed that some instructional methods were used more frequently for certain science subjects. For example, cooperative learning and experiment were more often used in physics and chemistry classes, while models and modeling were more often used in chemistry classes. This may indicate that some of the characteristics of a particular instructional method are more suitable for presenting different ideas to students. In the future, direct comparison or meta-analysis would be helpful to illustrate the correspondence between instructional methods and science subjects. Linking instructional method and subject characteristics in designing curriculum would lead to more effective conceptual change in students. In addition, these results suggest that science teacher educators have to be aware of the relationship between instructional methods and subjects when training future science teachers and help them transform their content knowledge into the most appropriate instructional representations and strategies (Shulman, 1986). For example, skills in "modeling with multimedia" might be more important for earth science teachers than for physics teachers. On the contrary, skills in experiments and laboratory safety might be more critical for the physics and chemistry teachers than for the earth science teachers. Besides considering the applicability of a particular instructional method to a specific subject, personal characteristics of the students might be an equally important factor. This largely ignored factor demands future investigation. Through further research, teachers could be equipped with suitable instructional methods for a specific subject when teaching students with certain personal characteristics.

In sum, the purpose of this study was to show how factors influence students' learning of complex and abstract scientific concepts and which factors might enhance conceptual understanding compared to other factors that might hinder students from constructing meaningful understanding of scientific phenomenon and theories. The results shed light on our understanding of the difficulty involved in changing conceptions during the learning trajectory.

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Appendix A: The comparative scope of the top 25 international highest impact articles (revised from Chiu, Lin, & Chou, 2016)

Rank	Frequency of Citation	Author (year)	Title (with conceptual change or not)		Source	Theoretical/ Empirical
1	199	Posner et al. (1982).	Accommodation of a scientific conception: Toward a theory of **conceptual change**.	Y	Journal	Theoretical
2	88	Strike & Posner (1992).	A revisionist theory of **conceptual change**.	Y	Journal	Theoretical
3	78	Pintrich et al. (1993).	Beyond cold conceptual change: The role of motivation beliefs and classroom contextual factors in the process of **conceptual change**.	Y	Journal	Theoretical
4	54	Carey (1985).	**Conceptual change** in childhood.	Y	Book	Theoretical
5	52	NRC (1996).	National Science Education Standards.	N	Book	X
6	50	Pfundt & Duit (1994).	Bibliography of every day conceptions and science education.	N	Data Bank	X
7	49	Hewson & Thorley (1989).	The Conditions of **conceptual change** in the classroom.	Y	Journal	Theoretical
7	49	Kuhn (1962).	The structure of scientific revolutions.	N	Book	Theoretical
9	46	Chi et al. (1994).	From things to processes: A theory of **conceptual change** for learning science concepts.	Y	Journal	Theoretical
10	44	Chinn & Brewer (1993).	The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction.	N	Journal	Empirical
11	42	Vosniadou (1994).	Capturing and modeling the process of conceptual change	N	Journal	Theoretical
12	40	Hewson (1981).	A **conceptual change** approach to learning science.	Y	Journal	Theoretical
13	39	Driver & Easley (1978).	Pupils and paradigms: A review of literature related to concept development in adolescent science students.	N	Journal	Empirical (misconception s)
14	37	Osborne & Freyberg (1985).	Learning in science: The implications of children's science.	N	Book	Empirical(misc onceptions)
15	34	Vosniadou & Brewer (1992).	Mental models of the earth: A study of **conceptual change** in childhood.	Y	Journal	Empirical
15	34	Nussbaum & Novick (1982).	Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy.	N	Journal	Empirical
17	33	Wandersee et al. (1994).	Research on alternative conceptions in science.	N	Book	Empirical(misc onceptions)
18	32	AAAS (1993).	Benchmarks for science literacy: A Project 2061 report.	N	Book	X
18	32	Driver et al. (1994).	Constructing scientific knowledge in the classroom.	N	Book	Empirical(misc onceptions)
20	31	Duschl & Gitomer (1991).	Epistemological perspectives on **conceptual change**: Implications for educational practice.	Y	Journal	Theoretical
21	30	Strike & Posner (1985).	A **conceptual change** view of learning and understanding.	Y	Book chapter	Theoretical
22	29	Tyson et al. (1997).	A multidimensional framework for interpreting **conceptual change** events in the classroom.	Y	Journal	Theoretical
22	29	diSessa (1993).	Toward an epistemology of physics.	N	Journal	Theoretical
22	29	White & Gunstone (1989).	Metalearning and **conceptual change**.	Y	Journal	Theoretical
22	29	Osborne & Wittrock (1983).	Learning science: A generative process.	N	Journal	Empirical (misconcep-tions)

Appendix B

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3. Allen, M. (2010). Learner error, affectual stimulation, and conceptual change. *Journal of Research in Science Teaching, 47*(2), 151-173.
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