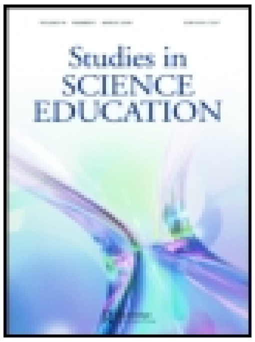

Studies in Science Education

ISSN: 0305-7267 (Print) 1940-8412 (Online) Journal homepage: https://www.tandfonline.com/loi/rsse20

Models of conceptual change in science learning: establishing an exhaustive inventory based on support given by articles published in major journals

Patrice Potvin, Lucian Nenciovici, Guillaume Malenfant-Robichaud, François Thibault, Ousmane Sy, Mohamed Amine Mahhou, Alex Bernard, Geneviève Allaire-Duquette, Jérémie Blanchette Sarrasin, Lorie-Marlène Brault Foisy, Nancy Brouillette, Audrey-Anne St-Aubin, Patrick Charland, Steve Masson, Martin Riopel, Chin-Chung Tsai, Michel Bélanger & Pierre Chastenay

To cite this article: Patrice Potvin, Lucian Nenciovici, Guillaume Malenfant-Robichaud, François Thibault, Ousmane Sy, Mohamed Amine Mahhou, Alex Bernard, Geneviève Allaire-Duquette, Jérémie Blanchette Sarrasin, Lorie-Marlène Brault Foisy, Nancy Brouillette, Audrey-Anne St-Aubin, Patrick Charland, Steve Masson, Martin Riopel, Chin-Chung Tsai, Michel Bélanger & Pierre Chastenay (2020): Models of conceptual change in science learning: establishing an exhaustive inventory based on support given by articles published in major journals, Studies in Science Education

To link to this article: https://doi.org/10.1080/03057267.2020.1744796

STUDIES IN SCIENCE EDUCATION
https://doi.org/10.1080/03057267.2020.1744796

Models of conceptual change in science learning: establishing an exhaustive inventory based on support given by articles published in major journals

Patrice Potvin [a], Lucian Nenciovici [a], Guillaume Malenfant-Robichaud [a,b], François Thibault [a], Ousmane Sy [c], Mohamed Amine Mahhou [a], Alex Bernard [a], Geneviève Allaire-Duquette [a], Jérémie Blanchette Sarrasin [a], Lorie-Marlène Brault Foisy [a], Nancy Brouillette [a], Audrey-Anne St-Aubin [a], Patrick Charland [a], Steve Masson [a], Martin Riopel [a], Chin-Chung Tsai [d], Michel Bélanger [a] and Pierre Chastenay [a]

[a]Équipe De Recherche En Éducation Scientifique Et Technologique (ÉREST), Université Du Québec À Montréal, Montréal/Canada; [b]Éducation, Commission Scolaire De l'Or-et-des-Bois, Canada; [c]Département des sciences de l'éducation, Université Du Québec À Trois-Rivières, Trois-Rivières, Canada; [d]Program of Learning Sciences, National Taiwan Normal University, Taipei, Taiwan

ABSTRACT

In this article, we propose an analysis of the state of, and trends in, the field of conceptual change research in science education through the lens of its models. Using a quantitative approach, we reviewed all conceptual change articles (n = 245) published in five major journals in the field of science education in search of the support that their authors give to conceptual change models (CC models). We looked for support in the form of explicit or implicit mentions, favourable and unfavourable position statements and empirical confirmations and refutations. The results present a thorough description of all types of support, as well as their evolution from the early days of the field to today. We also propose a hierarchical list of the 86 CC models that we have recorded, appearing in decreasing order by the support they received from the literature. General comments are formulated in order to provide an interpretation of the field and its evolution.

ARTICLE HISTORY
Received 25 April 2019
Accepted 31 October 2019

KEYWORDS
Conceptual change; models; science; review; inventory

Introduction

The issue of the specific difficulties that emerge while 'building new ideas in the context of old ones' (diSessa, 2006, p. 265) has existed for quite some time in the educational and educational psychology literatures. Linn (2008) suggested that 'conceptual change has perplexed and intrigued researchers at least since Rousseau (1892) and Locke (1824)' (p. 694). As early as the dawn of the 20^{th} century, Mach (1908) had already described in detail many of what today might be called *students' misconceptions* (i.e. representations that student's hold about the physical world and how it works), and proposed principles, such as the *economy of thought* (i.e. possible changes in representations while considering

CONTACT Patrice Potvin potvin.patrice@uqam.ca
Supplemenatal data for thisa article can be accessed here.

costs), by which the emergence and changes in conceptions could be constrained (Banks, 2004). Matthews (2002) even argued that the consideration of this issue can be traced back to as early as Socrates.

Even though it is generally associated with- and considered as a concern of- the English-speaking research community, the general issue of 'changing unconventional representations' is far from being exclusive to it. For example, in France, the research field of *didactics* (*la didactique*) became interested as early as the 70 s in students' systematic errors through classic studies such as the work of Viennot (1979). Viennot might be one of the first to have highlighted the relation between force and speed, that many students 'spontaneously' establish instead of between force and acceleration, 'despite being able to produce correct declarative knowledge' (Astolfi & Develay, 1998, p. 33). Another example can be provided from the other side of the planet: as early as the 1960 s, Japanese professor Itakura et al. (1964) suggested a pedagogical approach called 'Kasetsu', based on a kind of cognitive confrontation-with-predictions principle, that shares many properties with modern conceptual change approaches (Isabelle & De Groot, 2008; Tsukamoto, 2017). Thus, the general idea of conceptual change, even though it has taken many forms, appears to be far from new and far from exclusive to the Western world.

Nevertheless, it was in the 1970's that many of the most important contemporary conceptual change researchers (diSessa, 2006; Duit & Treagust, 2003; Vosniadou, 2008a) situated the incubation of the *conceptual change field*, through the emergence of increasingly productive research programmes that were systematically interested in the misconceptions that students display about natural phenomena in all scientific disciplines (Driver & Easley, 1978).

But it was in the early 1980's that the *foundation* of the field is usually pinpointed, when publications using the expression 'conceptual change' as a keyword or in titles began to appear. Indeed, the first references in ERIC of publications about 'conceptual change' date back to the year 1980, with propositions of authors such as the Hewsons (M. Hewson, 1981; P. W. Hewson, 1980) and Nussbaum and Novick (1981), who presented papers at the annual meetings of the *American Educational Research Association* (AERA) and the *National Association for Research in Science Teaching* (NARST). The first peer-reviewed articles on the topic were then published, among which we find the classic articles by Posner et al. (1982) and by Nussbaum and Novick (1982). These two articles are incidentally considered as having powered up – and set the standards for – the entire field that subsequently emerged (J.-W. Lin et al., 2016). And, indeed, they were followed in the next 4 or 5 years by many powerful contributions that are still frequently cited today. Many more studies followed and the field of conceptual change research reached its cruising speed in the mid-1990 s. Since then, the relative number of publications in the field has remained important but nevertheless have slightly and gradually decreased, sometimes by taking new forms and adopting new keywords. Extensive studies on research trends in the science education literature concerning the 'conceptual learning' research topic confirm a decline from 1998 to 2012 (T.-C. Lin et al., 2014), dropping from 1st place to 3rd. However, the field is still very productive and many educational research programmes around the world use this broad framework and are still striving to develop it (*EARLI/Sig-3* in Europe, *NARST/Strand-1* in North America, etc.) and even today, the 'Learning-Conceptions' research topic stills appears the top three in importance for the 2013–2017 period (Lin, Lin, Potvin & Tsai, 2019).

Meanwhile, teachers are still in need of concrete, effective and efficient solutions to the pedagogical difficulties and misconceptions that arise in their classes. Therefore the development of the research field of conceptual change remains crucial for the improvement of science education and thus for the all benefits that come with it, whether they be at the economic, social, environmental, etc. levels.

Among the ideological influences that have had the greatest impact on the development of the field, the following are often cited: Piaget's genetic epistemology (1968), Bachelard's epistemological obstacles (1967), Kuhn's scientific revolutions (1962), Festinger's cognitive dissonance (1957) and Toulmin's conceptual ecology (1972). Drawing on these influences (as well as on others[1]), many *conceptual change models* (hereafter identified as *CC models*) have been proposed over the years. These models have attempted to describe the *process* by which people exhibit changes (hopefully positive ones) in their beliefs about the nature of scientific objects and about the mechanisms that drive scientific phenomena. Among the most emblematic are Posner's (1982), Chi's (1992), Vosniadou's (1994), and diSessa's (1993) models. But many others have also been developed. These models are of great importance in understanding the field because they provide concrete illustrations of the main ideas that authors consider fundamental as well as providing effective educational prescriptions.

However, although such models are commonly found in comprehensive reviews and in the introduction and background sections of research articles, it is not easy to evaluate the approximate weight and level of recognition that each of these models has received, nor is it easy to evaluate the total number of them. Since no systematic evaluation of the level of support granted to each of the CC models has been yet carried out, the mere mention of a model in a publication brings not much more than an anecdotal argument in favour of its value.

Previous attempts at establishing conceptual change model inventories

Other than the brief, usual descriptions of the field that can be found in typical conceptual change articles, a certain number of peer-reviewed publications have nevertheless tried to provide 'broad as possible' overviews of all available perspectives of conceptual change, and many have offered argued commentaries about their respective robustness and popularity.

For example, Dole and Sinatra (1998) proposed a comprehensive review of many perspectives (*cognitive constructivist, social psychological*, and *derived from science education research*) of conceptual change before proposing their own model. Thorley and Stofflett (1996) also attempted to add their vision of the conceptual change model (CCM) to previous perspectives by enumerating all contributing ones. Unfortunately, these very relevant comprehensive initiatives are a bit outdated.

A very strong meta-synthesis was also conducted by Guzetti et al. nearly 25 years ago. In very large tables, they provided the results of their analysis of more than 46 important conceptual change articles. In this analysis, they identified the 'cited theory or model' (1993) that was used as the theoretical basis. However, some of the theories mentioned were very broad and domain-free (e.g., *Gagné*'s *learning hierarchy* [1977]), while others were very operational (*Posners* et al. *model*) or domain-specific. Therefore, the list is not specifically about models, but rather about general influences or trends, regardless of their nature.

Other summary analyses have also been carried out more recently from a historical perspective. Amin et al. (2014) for example, presented, in an extensive review, a general development of the field in three phases. Their analysis focuses on lists of components and constraints that influence learning, rather than on models themselves. diSessa (2006) and Vosniadou also proposed historical analyses of the development of the field, but they both candidly admitted that they did so, from their own 'side of the fence' (Vosniadou & Skopeliti, 2014, p. 1573). Unfortunately, neither of these contributions provides an objective basis for constructing inventories of CC models or for evaluating their respective weights.[2]

From our review, the study that provided one of the best systematic inventories of conceptual change models was that by Tyson et al. (1997). While not exactly up-to-date, this study attempted to 'synthesise various perspectives of contemporary conceptual change research' (p. 387) and provided, on page 390 (Figure 2), descriptive elements of no fewer than 10 'perspectives' (or models) of conceptual change, in which one can easily recognise all the classics, plus a few more. Havu-Nuutinen (2005) also proposed a list of ten 'theories' (along with their 'theorists') of conceptual change, that are presented in a table (p. 261), containing the classics, as well as other perspectives, such as Vygotsky's, however, without going further than 1999.

Another very exhaustive inventory was conducted by J.-W. Lin et al. (2016) on the basis of the number of citations for each of the 25 most popular articles about conceptual change published in the last 30 years. Even though this list includes many of the flagship articles about certain classic models (p. 2639), about half of the analysed articles do not focus on models. Such an approach of *counting citations* of articles dealing with the fundamentals of models could be a promising and efficient method of measuring the support given to each of the models. However, the complete presentation and development of many models is a process that often extends over more than one article. Furthermore, a citation does not necessarily denote positive or strong support. Also, the citation-counting approach does not necessarily control for the number of times an article cites a model. Indeed, some articles of criticism will contain a lot of information about their adversaries' perspectives. Therefore, counting citations as an indication of support could be misleading.

Considering all these reviews that were brought to our attention by various people from the field, we believed that it would be important to propose a complementary approach to all of the ones described above, in order to obtain a new portrait, for an unprecedented angle. We also believe that there is still a clear need for an *evaluation* of the relative support that is given by the research community for each one of the CC models. However, we do not believe that an attempt at arbitrarily evaluating by ourselves or with a grid the objective value, weight and historic trajectory of these models would be appropriate, nor free from criticism. To come to such an evaluation of the level of support given to each model, we instead propose to systematically study an important cross-section of the available literature, see when and how this literature supports CC models, and then come to a conclusion.

What counts as a model?

In the conceptual change literature, the presentation of conceptual change models is customary. However, the idea of a *model* is often used in a very casual fashion. It is true that many models (see above) certainly qualify as such without any need for careful or strict verification. Nonetheless, many other propositions might not. Thus a credible set of definition elements or criteria appears to be needed.

It is, however, difficult to find a consensual definition of a model. Usually, a *model* refers to the representation of an object or of a process. Since conceptual change is a process, a CC model will therefore strive to account for the *mechanisms* or *factors* that constrain and influence "the process by which 'students' initial ideas develop into more scientific notions' (Duit, 1999, p. 265). This rather cautious definition will provide a general frame for what a conceptual change model can be.

Since the models we are interested in describe processes, a mere practical recommendation provided by an author at a certain point should not be considered a model. Nor should a general epistemological or ontological commitment be considered as such, because this type of understanding or belief would not necessarily help put things into motion. In fact, a CC model has to describe a *movement* of minimal complexity from one state to another, or a *mechanism*, that unfolds through temporal steps or in a coherent structure, and drives this change. Therefore, a model can either be *descriptive* or *explicative* (of the process), *predictive* or *prescriptive* (focused on outcomes) or *exploratory* (partial or tentative).

Usually, the use of a CC model, like any educational intervention, should pursue an identified desired educational target (e.g.: make students realise that air has weight). But such an objective would not necessarily need to be made entirely *explicit*, nor completely achieved at the end of the process, because conceptual change can also be considered a progressively emerging phenomenon (Brown, 2014) and not necessarily a linear process with a definitive end point.

The different frameworks to which conceptual change articles usually belong are, with a few exceptions, of an *epistemological* or *instructional* nature (Chiu et al., 2016). Moreover, models are often either mostly *learning* models [like maybe diSessa's (1993) or Vosniadou's (1994)] or mostly *teaching* models [perhaps like Tsai's (2000) or She's (2004) models]. This can hamper an attempt to establish impervious repertoires of models, not only because usually no model is completely exclusive or opposed to others, but also because the objectives they pursue (to explain or provoke change) may be somewhat different in nature. Thus their juxtaposition in the same lists could be debatable, while remaining interesting.

It is also difficult to fix a model in time. Indeed, many models have evolved over the years. Even Posner's model was 'adjusted' by its authors a decade after its first publication (Strike & Posner, 1992). However, in the vast majority of these kinds of events, the adjustments were rather minor, so it usually remains possible to reduce without too much betrayal the evolution of a model to a single expressible proposition, usually presented in a few fundamental and convergent articles. A model is usually attached to a set of authors (very often led by one), but it is also possible for a single author or set of authors to have more than one model, if they are different enough. Finally, since very few models have been attributed to specific scientific disciplines (e.g., physics), and since most have been derived from very general learning principles or epistemologies, we will allow the juxtaposition of all acceptable models, regardless of the discipline in which they have been developed or are believed to have implications.

Finally, one has to acknowledge that CC models are rarely completely exclusive to all others. Indeed, many models are distinctive through only a few aspects or elements and many of them share some fundamental characteristics (e.g.: many of them give an important function to cognitive conflict). However, even if a comprehensive establishment of credible *families of models* would be certainly a worthy objective, we will differ this ambition for future efforts and consider all individual models as basic units of analysis.

For the purposes of this review, we have agreed to consider as CC models propositions that generally conform to the description presented above (see the methods section for the qualification algorithm), but we will also grant credibility to all claims that authors make about the qualification of any proposition as a model. We feel that, since our review study analyses peer-reviewed articles, all such claims could initially be presumed as minimally credible and should thus constitute the starting point of further analyses for qualification.

What counts as support for a model?

The support that science education/learning articles bring to a CC model can come in many forms. For example, it can be a single, isolated mention (or citation) of the model. In this case, the choice of making one mention instead of another one (or of not mentioning it at all) can, in our opinion, represent a notable recognition of its importance. It is not necessarily a strong recognition, though, and sometimes articles will only mention certain well-known components or aspects of certain models, while others will go further and proceed to a more thorough presentation of a model, for instance, by detailing its components, or explicitly identifying it as such. These two types of *support*, via an *explicit* or *implicit* mention, should be differentiated since they might serve different purposes in research articles; while some mentions often serve as theoretical bases later, others sometimes serve more secondary, almost decorative purposes. For example, an implicit mention refers to the identification of a model through deduction using indirect clues [e.g., *p-prims*] but with a fair level of certainty on the part of the analysts, while an explicit mention can be identified without doubt because it refers to the name of the model or to its author, etc. Sometimes it is also explained more thoroughly.

But some articles go further: mentions go beyond objective descriptions and are accompanied by value judgements. Support via a mention can thus be supplemented by *support by means of a position statement*. This support can either be positive or negative, with authors either arguing, for example, about the desirability or particular strengths of certain models, or criticising them, or pointing to their shortcomings and presenting them as such. This kind of support is widely seen in peer-reviewed position (or 'commentary') papers.

Finally, an article can bring *empirical support* to an existing model, through experimentation or quasi-experimentation that brings results that support it (or not). This kind of support is important, while also being tricky. Actually, sometimes *empirical support* can be brought to only one or a few components, aspects or steps of a model, rather than to the model as a whole. It can also be provided in mere absolute terms, like when increases in correct answers are recorded, but with no comparison with a control group. It can also be provided in relative terms. For example, results can be contrasted with situations of a different nature, such as with a control group where nothing special happens, where another CC model is tested, or where an often ill-defined 'traditional teaching' treatment is applied, and so forth. It is therefore clearly debatable to put in the same bag experimental pieces of evidence that are of differing natures. Nevertheless, for now and for the purpose of the feasibility of our study, we will count as one *empirical support* a peer-reviewed article that brings at least one positive (*confirmation*) or negative (*refutation*) argument of any empirical basis. We will thus postpone any evaluation of the quality of the results and methods found in selected experimental and quasi-experimental articles.

Research questions

In light of the context presented above, our research questions are

- (Q1) how many articles (found in selected major educational/learning journals) provide support to each CC model in science learning, through
  - an explicit [Q1a] or implicit [Q1b] mention,
  - a favourable [Q1c] or unfavourable [Q1d] position statement, or
  - empirical methods that bring confirmation [Q1e]) or refutation [Q1f] arguments?
- (Q2) how have these types of support [Q2a-Q2f] changed over time, throughout the history of the field? And
- (Q3) what ordered list (inventory) of CC models emerges from such an analysis?

We believe that answering to these questions in 2019 will allow today's researchers to better understand the recent evolution of their field and to situate their own work within actual trends. It will also allow an appreciation of the level of credibility that peer-reviewed publications give to the diverse conceptual change propositions of the past. In the context of an apparent decline of the number of CC articles, providing such answers could also nourish a reflection about the future of the field and what can be done to keep it healthy.

Methods

Selection of articles for the corpus

We chose to limit our search to peer-reviewed articles that were indexed in the *Education Resources Information Centre* (ERIC) and *PsycINFO* databases, the two databases we believed contained most of the conceptual change scientific contributions. After three discussion sessions involving four experts in science education (science didactics), the algorithm ['conceptual change' AND (science* OR physics OR chemi* OR biolog*)] was chosen and used in order to cover most of the articles in which titles, abstracts or descriptors (keywords) contained the general idea. Adding other scientific disciplines did not increase the number of articles. We also tried adding 'conceptual learning' as a descriptor, but it yielded a large number of 'non-conceptual change' articles, so we decided to keep only conceptual change in the algorithm. This database search was conducted (for the last time) on 6 April 2018 and provided a total (for the two databases) of 1,100 results.

In order to keep this review manageable, we then decided to keep all articles belonging to the five research journals containing the most articles. This shortened our list to 302 articles. After a pre-analysis phase, we decided to reject some of them (57), because some were introductions of special issues, were *errata* or announcements of awards given, but also because others were not necessarily about learning/teaching science (some were about teacher training, misconceptions about pedagogical content knowledge [PCK], or others were in mathematics).

Development and validation of the rubric and guide

In light of the research questions, an analytic rubric was developed using Microsoft Access© software by a team of three experts involved in the project. It was iteratively modified many times, and then pretested with five articles (two theoretical, three empirical). It was also amended slightly during the analysis, but not to the point of threatening data previously recorded.

This rubric came with a 10-page analysis guide (iteratively developed by a team of five) that was used by all analysts during the entire procedure. This guide explained, among other things, how to identify different types of support. For example, it specified that articles that provided *support via an explicit mention* had to 'clearly refer to a model' (the words 'theory', 'model', 'view' or 'perspective' were considered acceptable), to 'refer to elements of the model that were exclusive to it', to 'refer to a family of models, but specified that such model was a part of it', or to 'occupy an important place in the presented research'. The guide also specified that *support by implicit mention* were to be recorded if 'articles being considered cited certain models or certain of its fundamental texts, but without identifying them explicitly as models'. The guide also contained warnings such as 'in case of doubt, it is better to abstain', and provided examples and counter-examples of what did or did not qualify for each type of support.

The guide also informed analysts about how to record 'models for which the author has expressed (positive or negative) position statements' and to take note of all reasons given. And finally it guided the analysts by specifying the criteria that make empirical support acceptable: 'The model gets empirical support if the author has clearly concluded that there were positive (or negative) effects [...]', 'if more than half of the participants in the experimental condition have shown positive effects on learning', or 'if the model is explicitly deemed as providing (or not) a promising way of interpreting data' (such as through qualitative analyses). All materials are available through the corresponding author.

Analysis of the corpus

Each analyst involved was trained for one day to understand and use the rubric and the guide. Every time a new analyst was involved in the project, he or she had to be paired with a more experienced one. All analysts worked in the same room and had regular meetings and discussions about the best way to record their findings. A total of 11 people, all from the field of education, were involved in the process.

Each article was read and analysed separately by at least two analysts. One analysis by one analyst took on average a half a day of work. The two analysts then met and shared their individual recordings. We estimate that the initial agreement between coders reached nearly 90%. They then discussed what should and should not be recorded in the database until they reached consensus on all elements. When they could not agree on certain elements (for example, whether or not to record a case of experimental support), a third experienced analyst joined the discussion until agreement was reached.

For purposes of clarity of the presented results, a 3-year smoothing of the data was performed. A similar smoothing was also performed on all figures in the 'results' section that involve time.

Concomitant development of the list of CC models

As analysts recorded support for a model (or potential model) that had not been encountered before, verification of its qualification as a CC model was systematically carried out. Analysts examined all the fundamental texts (regardless of their initial presence in, or possible absence from, the selected corpus) that described these propositions and used a decision tree (see Figure 1) to determine qualification. The verification process was carried out by at least two analysts working together who had to reach agreement before recording the proposition as a CC model in our database. The entire recording of the characteristics of a model took an average of a half day's work for two people.

This qualification solution may be considered rather permissive and therefore too inclusive. However, this was intentional, as we wanted to ensure that no credible model would elude our analysis. We preferred to have more Type I errors (false positives) than Type II errors (false negatives), and will thus accept the consequences that come with this choice.

Results

Description of the corpus

The final corpus contained 245 articles (186/245 articles were about empirical research and 59/245 were exclusively of a theoretical nature), distributed across the five richest (in terms of relevant articles) journals (*see* Table 1).

Figure 2 shows the distribution over time of the articles within the five selected journals.

This distribution suggest that the 1992–1994 span has seen, after a decade of incubation, an abrupt acceleration of publications, mostly in three journals. For the following years, the situation remained fairly stable, and then a progressive decline can be observed, especially in the last considered years. The participation of the five journals to the field appears somewhat uneven, except maybe for the JRST.

Support for models (Q1 & Q2)

In the entire corpus, a total of 2,156 instances of support of all types were recorded (1,962 positive and 194 negative). These instances of support were distributed across all categories according to Table 2.

Without much surprise, most support is provided through explicit mentions (40.5%), followed by implicit ones (19.5%). Favourable position statements and empirical confirmations are equally proficient (15-16%) and 'negative' supports (unfavourable position statements and empirical refutations) remain somewhat marginal despite their epistemological importance.

Explicit mentions (Q1a & Q2a)

Figure 3 shows, in decreasing order, the number of articles (out of 245) that mention each recorded CC model and explicitly present them as such. It is important to remind readers that this figure (as well as the following) does not show the number of such mentions, but the *number of articles* that make such mentions at least once, usually in their introduction, background, or theoretical framework sections. It is also important to understand that each article can provide support for, or critique of, more than one CC model.

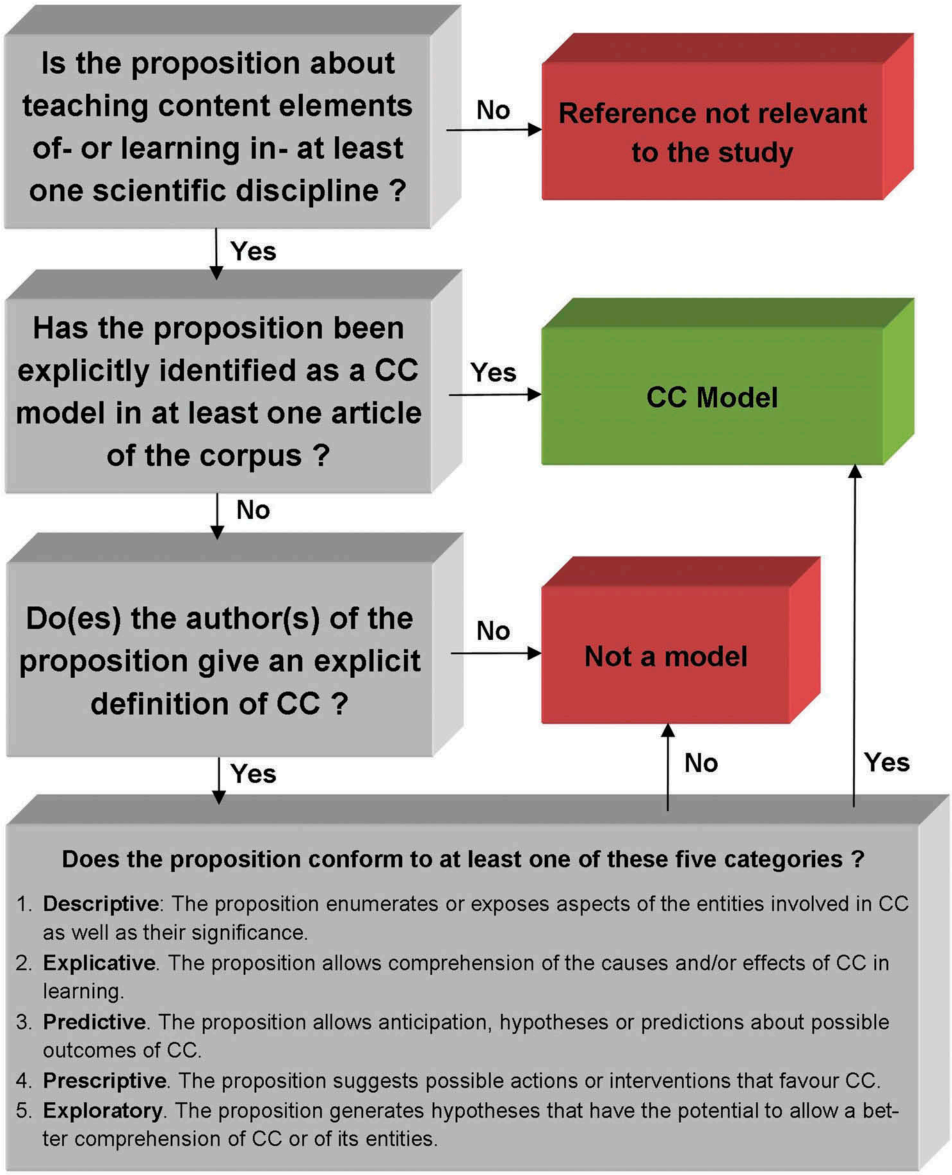

Figure 1. Decision tree used to qualify models of CC in science education.

The colours used to identify the models are the same in all the figures in this paper (e.g., Posner et al.'s model is always in black and Vosniadou's in red, etc.). All these figures include self-mentions (self-citations), because we believe that, since articles published in the journals under consideration have undergone thorough, blinded evaluation processes carried out by experts in the field, we can be surer of their objective value, regardless of the presumed subjectivity of self-citations.

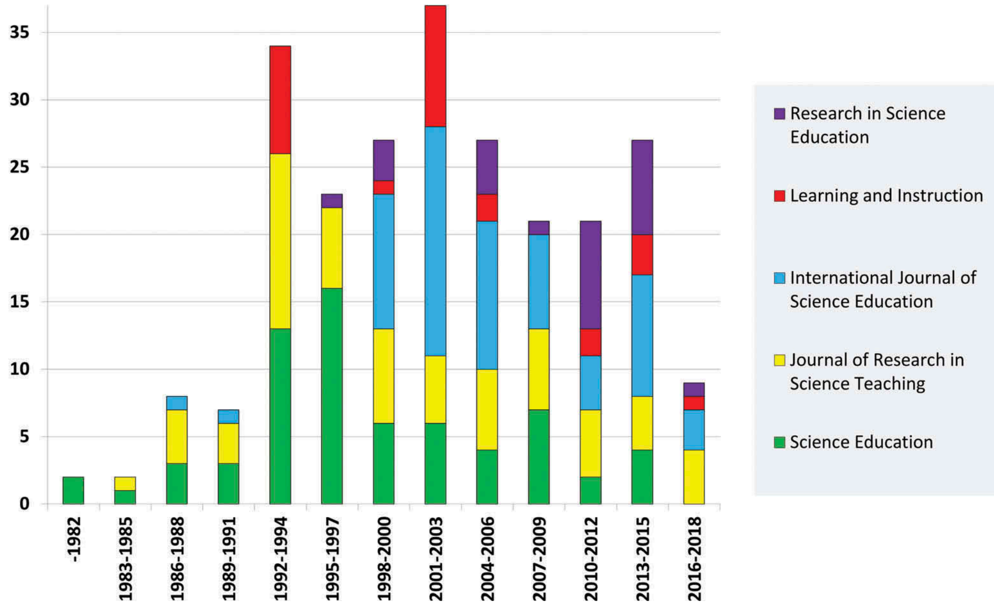

Figure 2. Distribution over time of articles within the five journals.

Table 1. Journals selected and number of articles selected in each.

Journal selected	Number of articles selected	% of articles selected
Science Education (SE)	67	27.3%
Journal of Research in Science Teaching (JRST)	64	26.1%
International Journal of Science Education (IJSE)	63	25.7%
Learning and Instruction (L&I)	26	10.6%
Research in Science Education (RISE)	25	10.2%
Total	245	100.0%

Table 2. Distribution of all recorded instances of support across the six categories.

Type of support	Number of instances of support recorded	% of instances of support recorded
Explicit mention	873	40.5%
Implicit mention	420	19.5%
Favourable position statement	344	16.0%
Unfavourable position statement	125	5.8%
Empirical confirmation	325	15.1%
Empirical refutation	69	3.2%
Total	2,156	100%

Figure 3 allows to easily identify the most ‘popular’ models that are explicitly referred to in our set of selected articles. On top, Posner’s model (black) appears to be far ahead; almost twice more often cited that any other model.

Figure 4 shows the distribution over time of articles providing support via explicit mentions. They appear in the same decreasing order (however from bottom to top) as the one provided in Figure 3. To retrieve each model, one can refer to the colour used (same for all figures), or to the abbreviation used, associated with each model presented in Table 3.

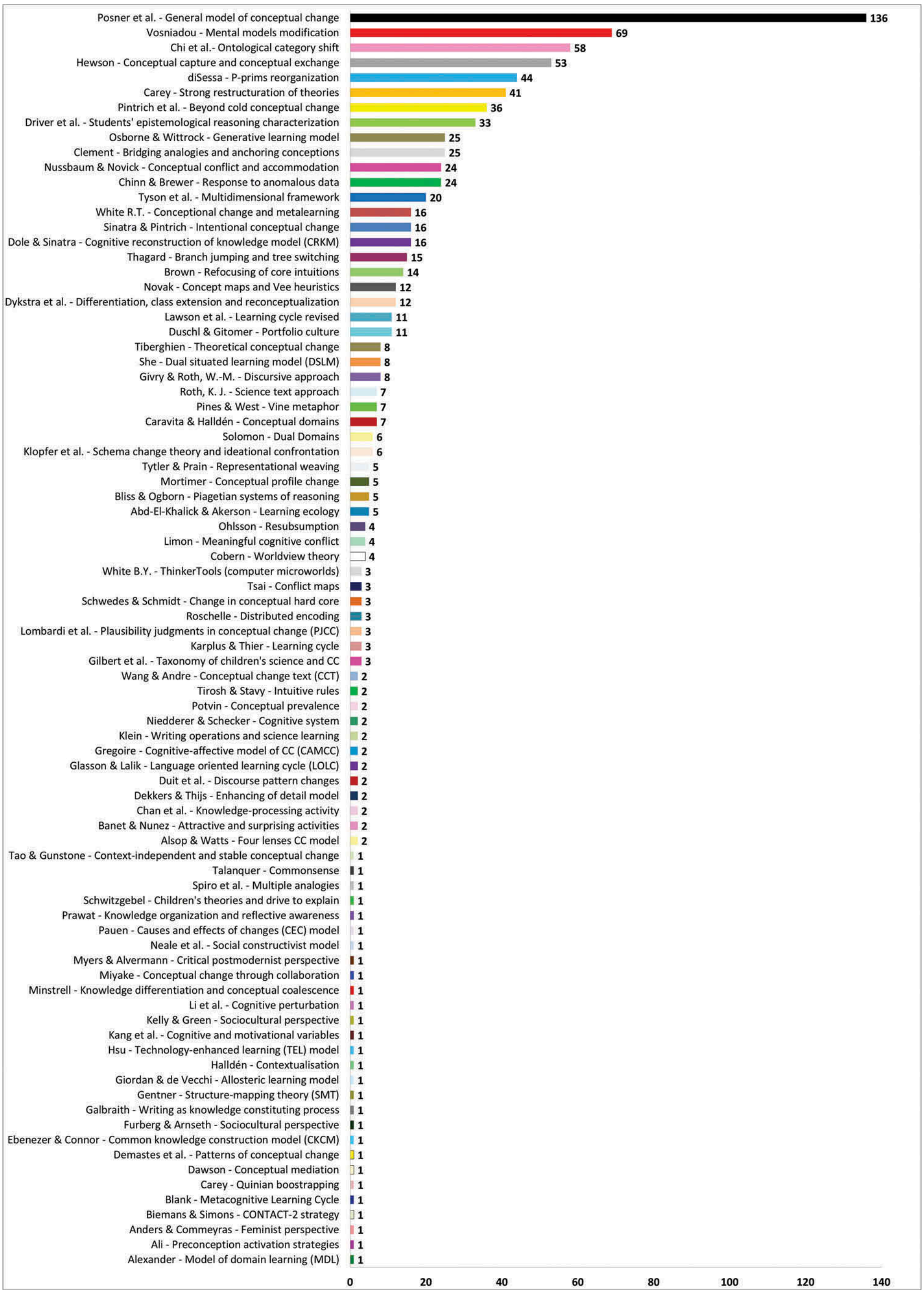

Figure 3. Number of articles providing support via an explicit mention for each CC model.

It is not impossible that recorded mentions occur a few years before the official introduction of a model, because sometimes authors had the opportunity to hear about key elements of early versions of rival models in conferences. After verification, this happened two times (1 example of support for VOS and another for DIS), both preceding the definitive versions of these models by about two years. Figure 4 shows an uneven distribution of explicit mentions, with most popular models also being the oldest ones.

Implicit mentions (Q1b & Q2b)

Figure 5 shows, in decreasing order, the number of articles (out of 245) that mention each recorded CC model in an implicit way, meaning that they can mention fundamental aspects of certain models and of their distinctive elements, but without explicitly identifying them as models. It is important to understand that these results are not as strong as the ones compiled for explicit mentions because they are more a function of the analysts' interpretation and their familiarity with CC models. Indeed, the identification of implicit mentions have caused more intense discussions between coders than explicit ones, mostly because they require deductions about the author's intentions and because they rely on indirect clues. Thus, they can be farther away from authors' intentions. It is also important to understand that all the results given for implicit mentions are entirely exclusive of those obtained via an explicit mention. This means that a model that received an implicit mention in an article necessarily *did not* get an explicit one. Thus, Figures 5 and 6 cannot be considered independently from Figures 3 and 4.

Implicit mentions show, among other things, a distribution quite different from explicit mentions, with Driver's model appearing in first place, instead of Posner's, but with less

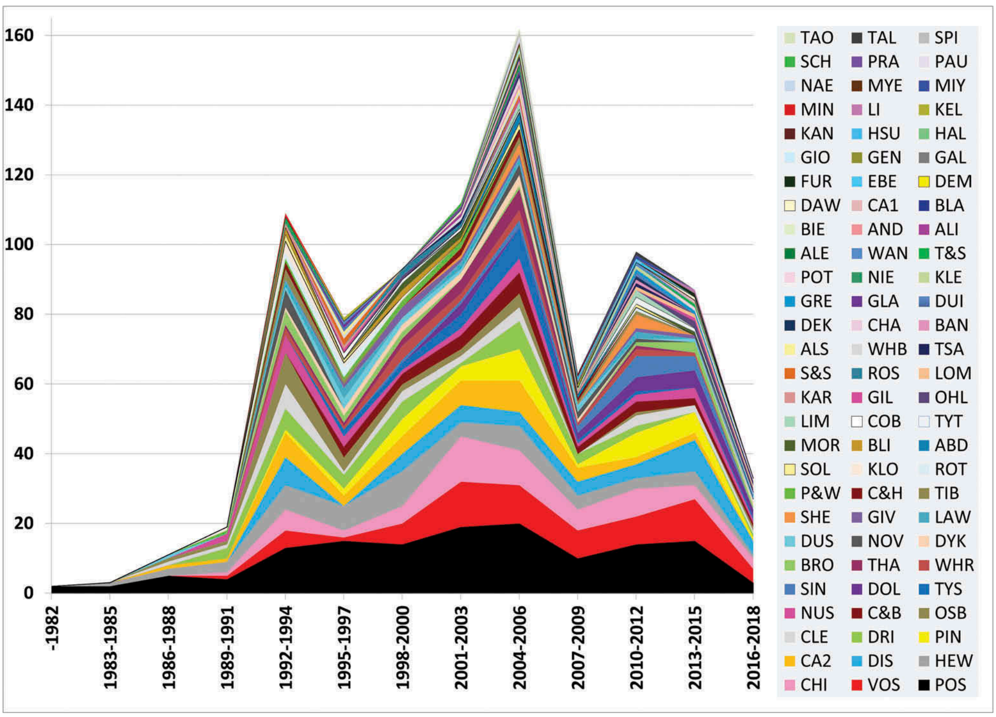

Figure 4. Distribution over time of articles providing support via an explicit mention for each CC model.

clear quantitative superiority. Figure 6 shows the distribution over time of recorded articles providing support via an implicit mention.

Since the 1992–1994 explosion of articles described before, most implicit mentions seem to have recorded a stable number, with a peak during the 2001–2003 span. This contrasts a bit with the explicit mentions graph (Figure 4), in which a peak appeared a bit later (2004–2006). Implicit mentions also seem to be less concentrated on a few models and more evenly distributed between models.

Favourable position statements (Q1 c & Q2 c)

Figure 7 shows, in decreasing order, the number of articles (out of 245) providing support for each recorded CC model via a *favourable position statement*. Therefore, when an article has explicitly presented a model, or one or more of its elements or outcomes as positive, interesting, valuable or desirable, it appears in this summation.

Favourable position statements appear to follow the same pattern as explicit mentions. This might possibly be due to the general observation we made that explicit mentions and favourable position statements often come together, while being logically exclusive.

Figure 8 shows the distribution over time of recorded articles providing support via favourable position statements. Also for the distribution in time, that general pattern of favourable position statements appears to follow the same one as explicit mentions.

Unfavourable position statements (Q1d & Q2d)

Figure 9 shows, in decreasing order, the number of articles providing unfavourable value judgements of certain models. Therefore, when an article has explicitly presented a CC model or one or more of its elements or its outcomes as negative, discredited or undesirable, it appears in this summation.

Surprisingly, the unfavourable position statements are mostly concentrated on the popular models, the most criticised one being Posner's model; however with the exception of the diSessa models, which is the second most criticised, while clearly not being in second place in other figures (see the Discussion section for more).

For purposes of reducing text length, the distribution over time of recorded articles providing unfavourable position statements, by model is presented in supplementary materials (under 'Unfavourable position statements – time').

Empirical confirmation (Q1e & Q2e)

Figure 10 shows, in decreasing order, the number of empirical articles (out of a possible 186) providing empirical confirmation of certain models. Therefore, when an article has explicitly presented empirical results that clearly or explicitly support one model, this model appears in the figure. Such empirical support types are usually found in the analysis, interpretation, discussion or conclusion sections of the articles under analysis. If an article argues that its results support more than one model, then we recorded support for each one of these models.

Posner's and Vosniadou's models are clearly the ones that get the most empirical support from articles. While the quality of this support is not evaluated, we can

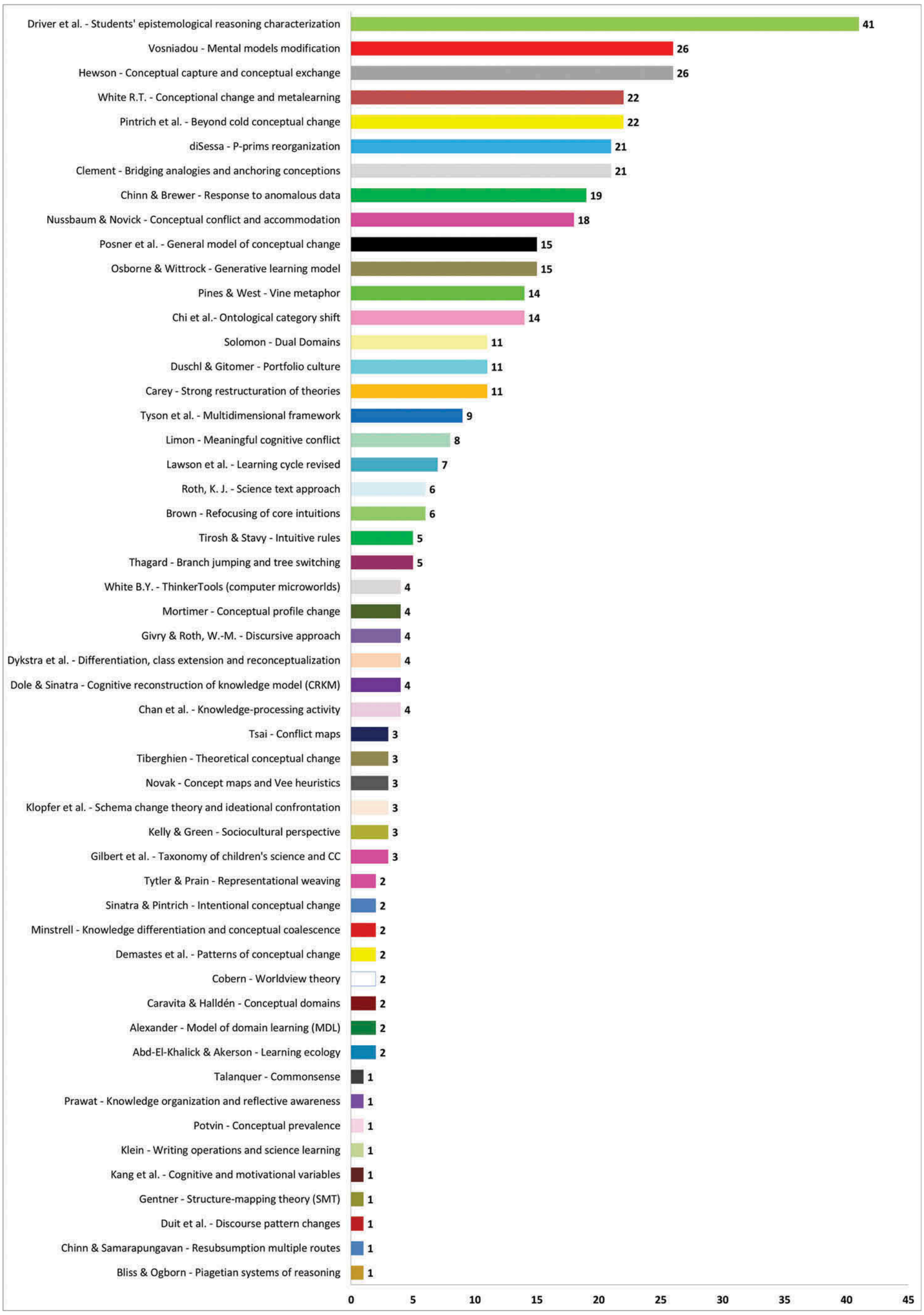

Figure 5. Number of articles providing support via an implicit mention for each CC model.

nevertheless affirm that more empirical articles provide support to these two. Many other models also benefit from empirical support, but most of the ones that only get only one instance of empirical support are often ‘proven’ only by their proposers.

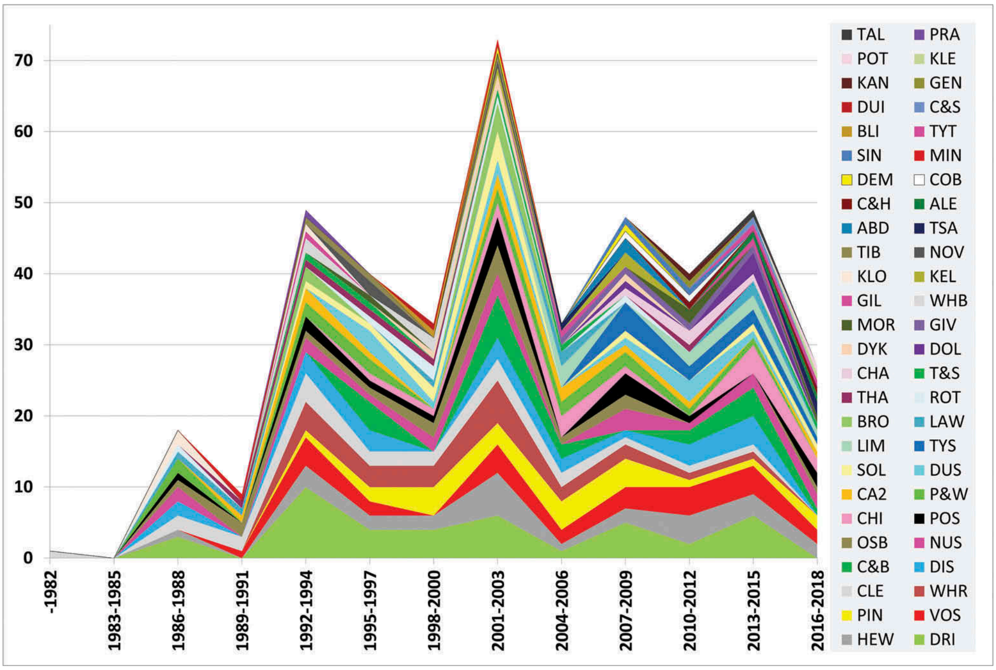

Figure 6. Distribution over time of articles providing support via an implicit mention for each CC model.

Figure 11 shows the distribution over time of recorded articles providing empirical confirmation, by model.

This distribution in time of empirical confirmations suggest that their targeting is sometimes concentrated during certain periods. For example, Hewson's model has been tested mostly during the 1992–2000 period, while Carey's (CA2), mostly from 2001 to 2009. Surprisingly, Posner's model does not seem to benefit from much of this type of confirmation anymore.

Empirical refutation (Q1 f & Q2 f)

Figure 12 shows, in decreasing order, the number of articles (out of 186) providing empirical refutation of certain models. Therefore, when an article has explicitly presented empirical results that clearly or explicitly refute a model or one of its elements or possible outcomes, this model appears in the figure.

Empirical refutation are rather rare events in the field of conceptual change. Most of them are concentrated on Posner's, Chi's and Vosniadous' model, in decreasing order. Since their relative scarcity, and for purposes of reducing text length, the distribution over time of recorded articles providing empirical refutation (by model) is presented in supplementary materials (under 'Empirical refutation – time').

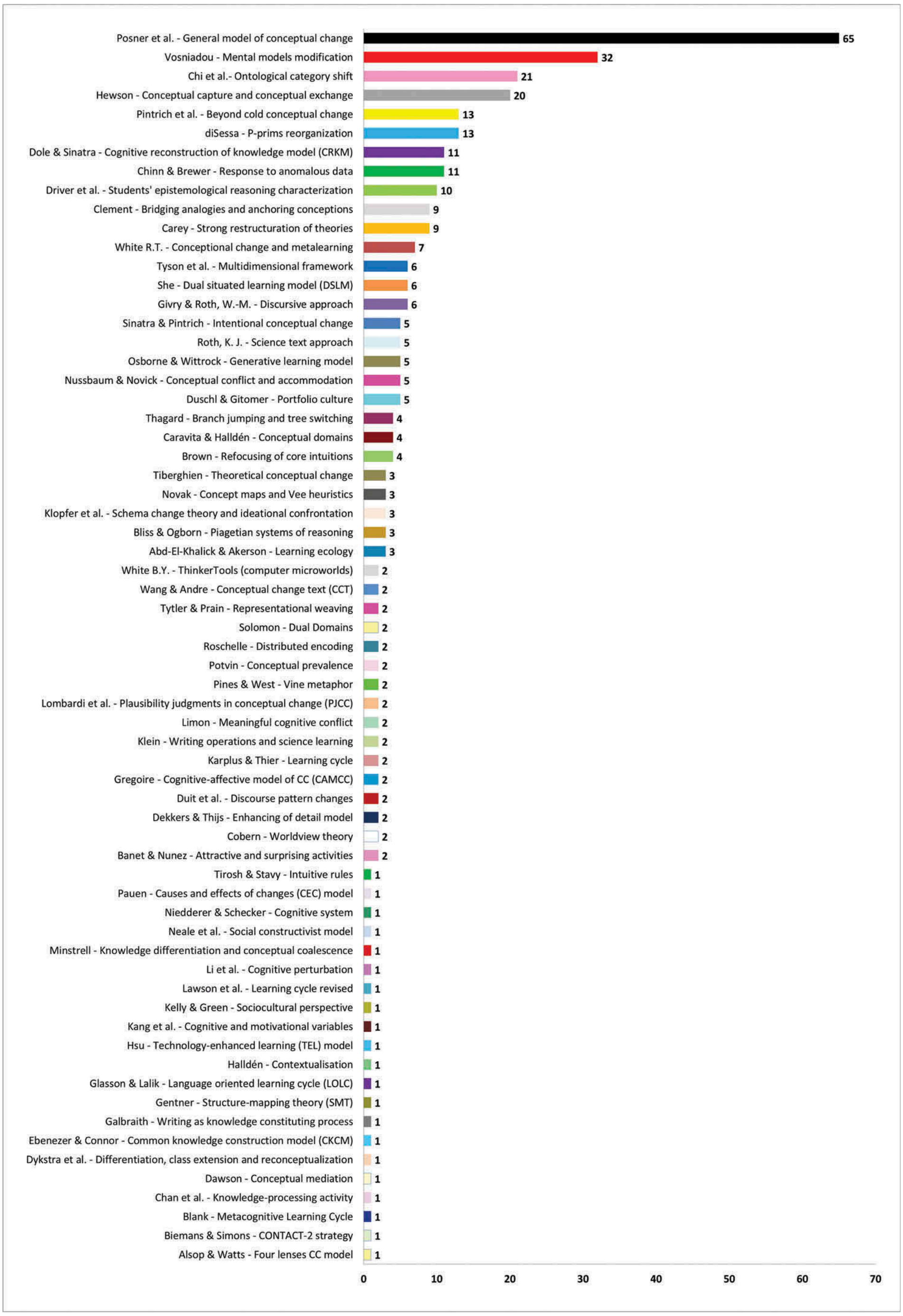

Figure 7. Number of articles providing favourable position statements for each CC model.

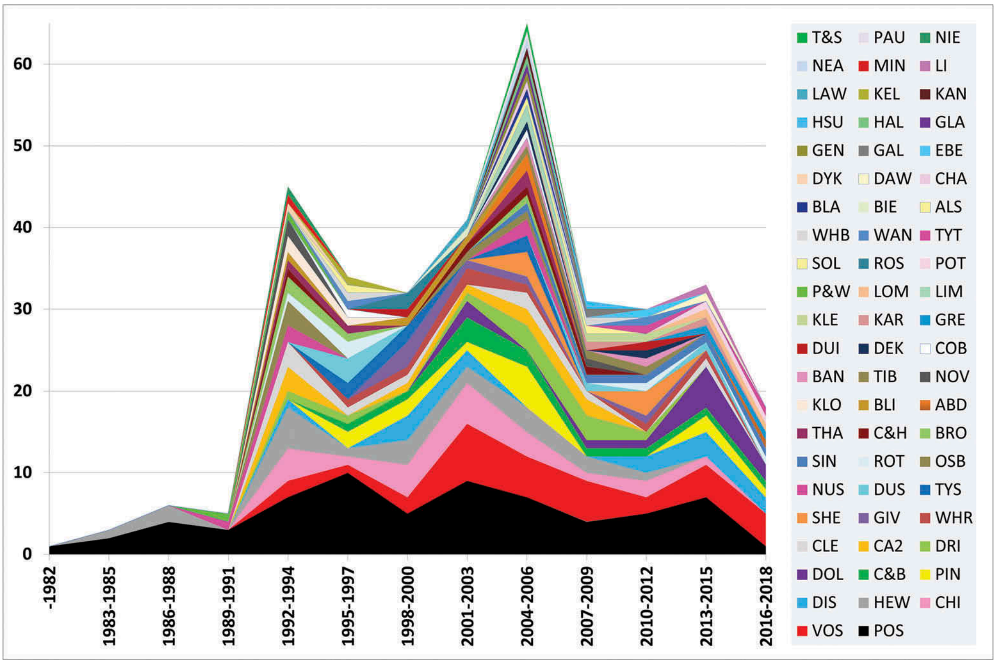

Figure 8. Distribution over time of articles providing favourable position statements for each CC model.

List of CC models (Q3)

Table 3 presents the complete list of qualifying models (n = 86) with a suggested identifying label, the codes used to retrieve them in this article (abbreviation and colour), and a recommended fundamental reference article to allow the reader to easily find at least one of the best (to our knowledge) descriptions of them. We also offer a very short description of the supposed mechanism of conceptual change (which has not been confirmed by the proposers of the models; we hope we have remained faithful to their main ideas). The table also details the number of all favourable supporting articles that each CC model received from the corpus. It is on the basis of these numbers that we established the hierarchy, the ones on top – those with the most support – being determined by empirical support. If the number of support examples was identical, positioning was determined by the number of favourable position statements. In case of a tie, explicit mentions were used. Implicit mentions, and then alphabetical order were also used a few times to distinguish between the last remaining models where there was a tie.

Discussion

General comments on the corpus and its evolution over time

Looking at Figure 2, we can see that, although articles explicitly identified as conceptual change (in science learning) began to be published in the early 1980 s, the early '90 s saw an 'explosion' of research propositions on the topic. It is possible that the initial

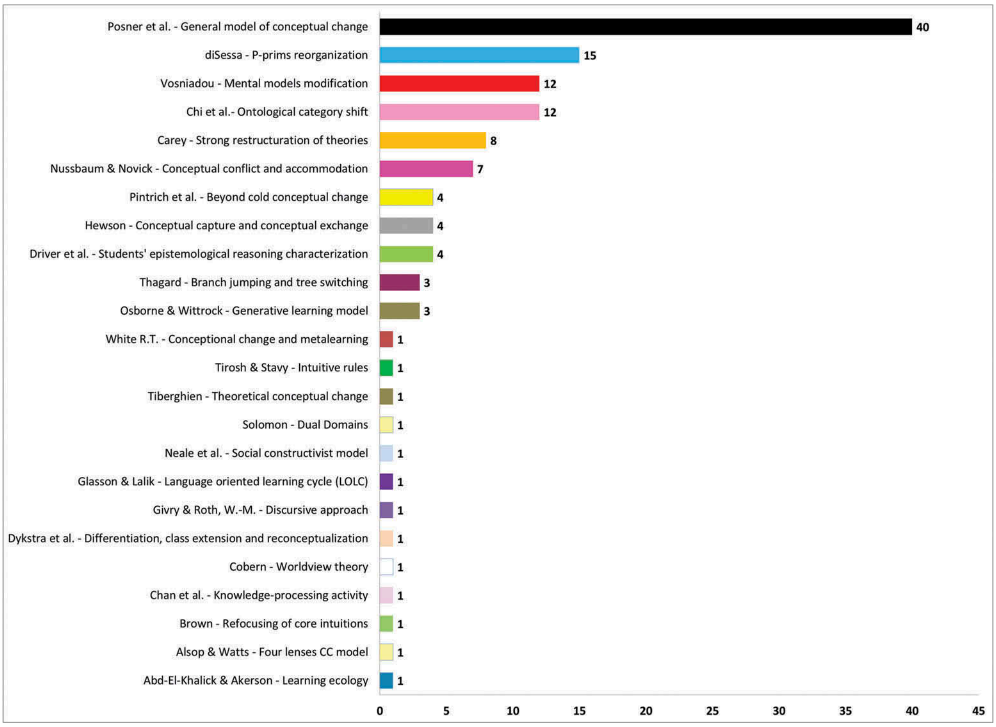

Figure 9. Number of articles providing unfavourable position statements for each CC model.

publications on the topic (with the publications of special issues), triggered this apparent enthusiasm. However, it is also possible that such interest in frequent-yet-logical errors already existed, but that the appearance of the 'conceptual change' framework had a consolidating effect on the previously dispersed initiatives within the field of science education. This enthusiasm seems to have declined starting in the early 2010 s, but conceptual change was still an important topic, with an apparent regain in interest between 2013 and 2015. However, the weak score for 2016–2018 should not necessarily be considered, at this point in time, as a second decline in interest, as all articles for this period may not have been published yet, and because indexation in databases can be subject to delays.

The distribution across the different journals appears to be a bit noisy, and even if all the journals selected have published conceptual change articles in nearly all the periods considered, these numbers do not show much regularity. However, this can be explained by the fact that sometimes journals publish special issues [for example, *Learning and Instruction*, which published a conceptual change special issue in 2001 (Mason, 2001), the presence of which clearly appears in Figure 2], or make explicit or implicit changes in their policies or publication habits, as well as in their regular production cycles (e.g., changes in personnel can have noticeable effects on publication standards or productivity). Nevertheless, our data seem to indicate a rather regular rate of publication of conceptual change articles, with what seems to be a peak in the early 2000 s.

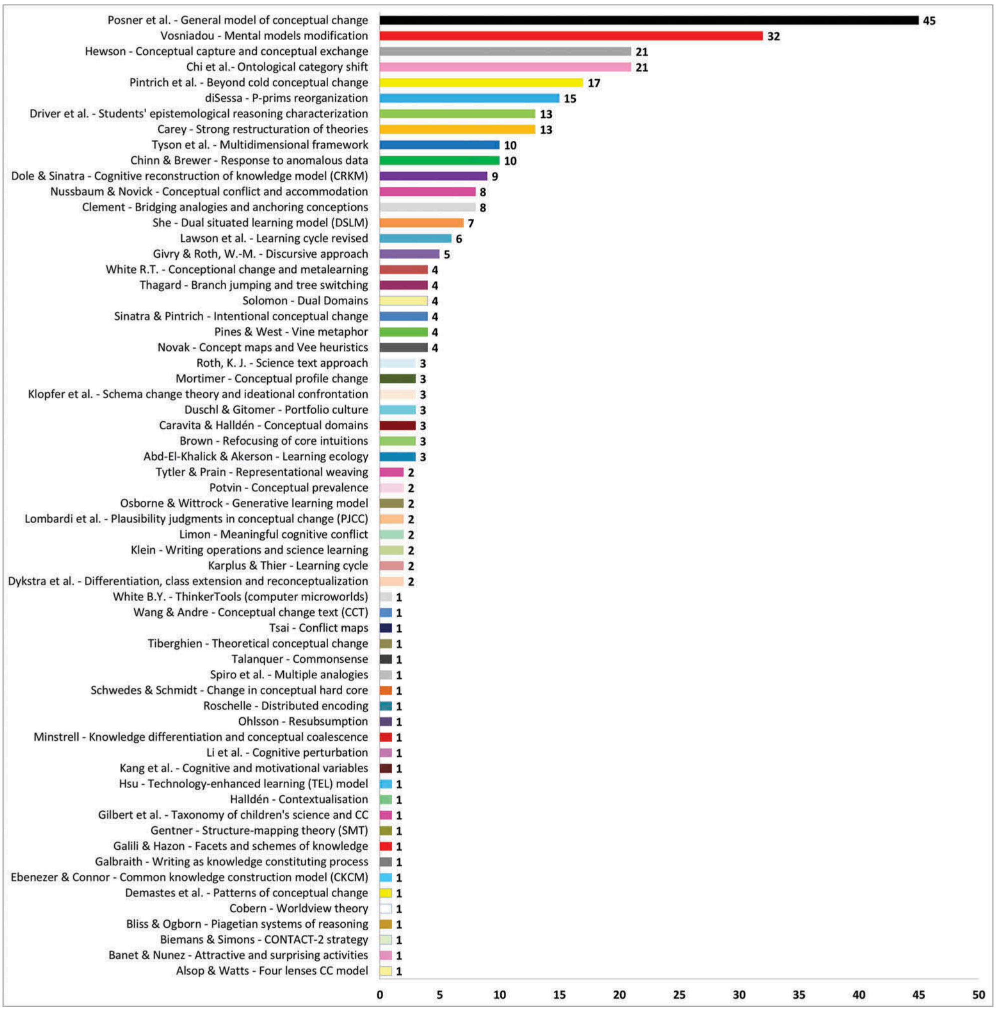

Figure 10. Number of articles providing empirical confirmations for each CC model.

The vast majority of these articles refer (explicitly or not) to models of conceptual change. Knowing that we recorded 2,156 distinct examples of support of all types (Table 2), and that we analysed 245 articles to get them, we can calculate a mean of almost 10 distinct references or examples of support for CC models in each article. Most of these supports are mere mentions (873 + 420 = 1,293), and many (344 + 125 = 469) are also accompanied by value judgements (regardless of the legitimacy, the nature or basis of these judgements). But we can also record many (325 + 69 = 394) empirical arguments that confirm or refute CC models. We can therefore hardly accuse the field of referring exclusively to ideology.

Models with the greatest support and influences

By examining Figure 3, one can see that our corpus uses explicit mentions to refer to certain models much more often than to others. Indeed, and with little surprise, more

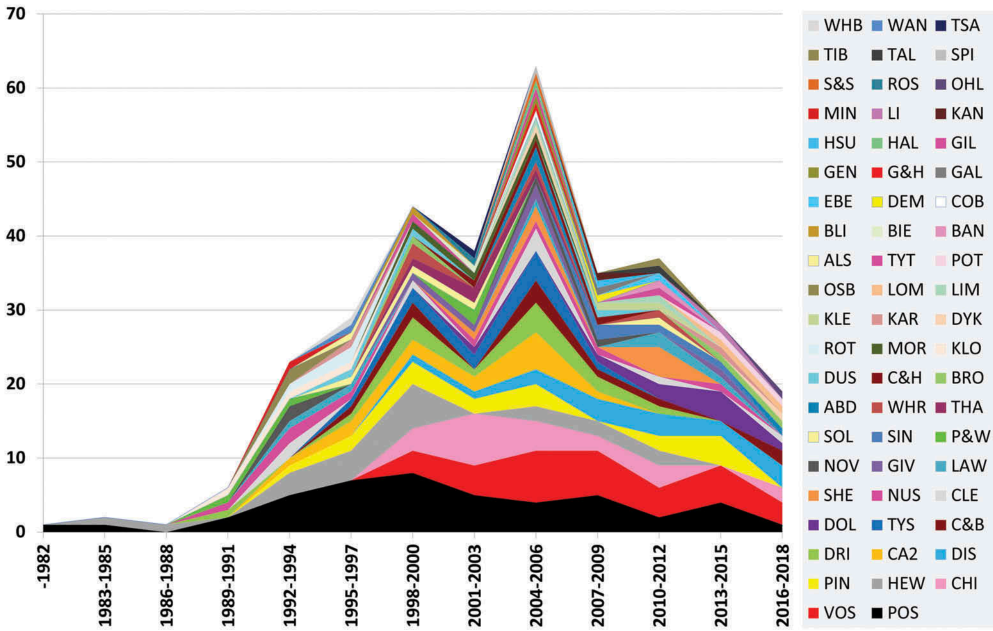

Figure 11. Distribution over time of articles providing empirical confirmation for each CC model.

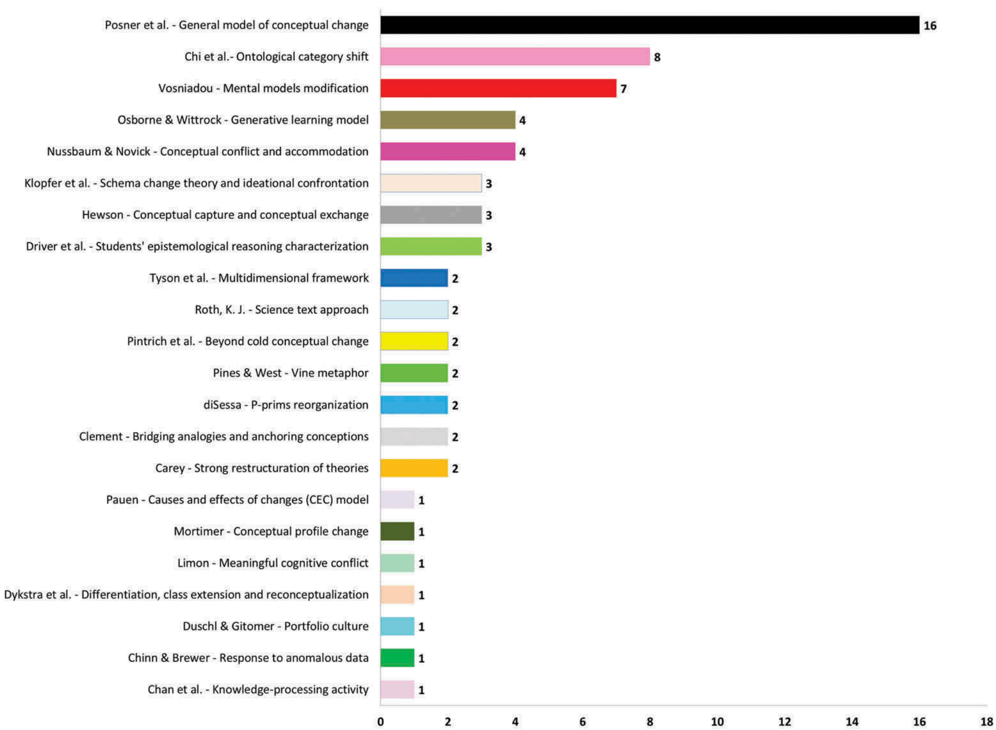

Figure 12. Number of articles providing empirical refutation for each CC model.

Table 3. Ordered list of CC models.

Rank	Author(s) - Name of the model	Codes	Recommended reference for understanding the model	Short description of the mechanism by which CC occurs	Empirical support (N)	Favourable position statement (N)	Support by explicit mention (N)	Support by implicit mention (N)	Total recorded positive examples of support (N)
1	Posner et al. - General model of conceptual change	POS	(Posner et al., 1982)	CC consists of people's central, organizing concepts in the conceptual ecology changing from one set of concepts to another set, incompatible with the first. Four conditions are necessary: (1) dissatisfaction with the pre-existing concept; new concept perceived as (2) plausible, (3) intelligible and (4) fruitful.	45	65	136	15	261
2	Vosniadou - Mental model modification	VOS	(Vosniadou, 1994)	CC consists of the gradual modification of one's mental models of the physical world, achieved either through enrichment or revision. Enrichment involves adding new information to existing conceptual structures. Revision involves changes in individual beliefs or presuppositions or in the relational structure of a theory.	32	32	69	26	159
3	Chi et al. - Ontological category shift	CHI	(M. T. H. Chi, Slotta, & De Leeuw, 1994)	Entities in the world can be classified according to three ontological categories (matter, processes, mental states). CC is the reassignment of a concept's categorical membership across ontological categories, mostly from the category of matter to the category of processes.	21	21	58	14	114
4	Hewson - Conceptual capture and conceptual exchange	HEW	(P. W. Hewson, 1980)	A new conception can be "captured", i.e., incorporated into existing conceptions if intelligible/plausible/fruitful. If the new conception contradicts existing conceptions, its acceptance is blocked. For a person to accept it, the status of blocking conceptions has to lower before the status of the new conception rises, in a "conceptual exchange".	21	20	53	26	120
5	Pintrich et al. - Beyond cold conceptual change	PIN	(Pintrich, Marx, & Boyle, 1993)	The CC process is mediated via the dynamic interplay of three types of factors: motivational (e.g., personal interest), classroom contextual (e.g., task structures) and cognitive (e.g., activation of prior knowledge).	17	13	36	22	88
6	diSessa - P-prims reorganization	DIS	(diSessa, 1993)	CC consists of the reorganization of phenomenological primitives (p-prims) into a larger cognitive system. P-prims are small, fragmentary causal relationships forming the naive sense of mechanisms in intuitive physics.	15	13	44	21	93
7	Driver et al. - Students' epistemological reasoning characterization	DRI	(Driver, Leach, & Millar, 1996)	Nature of students' scientific knowledge is represented via 3 epistemological representations: (1) phenomenon-based reasoning; (2) relation-based reasoning; and (3) model-based reasoning, each linked with distinct ways of portraying scientific enquiry and the nature of scientific explanation. Scientific knowledge is socially constructed.	13	10	33	41	97
8	Carey - Strong restructuring of theories	CA2	(Carey, 1985)	CC occurs via strong (rather than weak) restructuring of children's theory-like conceptual structures through three processes: (1) replacement of the initial concept by a new one; (2) differentiation, in which the initial concept splits into two or more new concepts; and (3) coalescence, in which two or more initial concepts form a single concept.	13	9	41	11	74
9	Chinn & Brewer - Response to anomalous data	C&B	(Chinn & Brewer, 1993)	Seven forms of response to anomalous data are possible: (a) ignoring it; (b) rejecting it; (c) excluding it from current theory; (d) holding it in abeyance; (e) reinterpreting it; (f) making peripheral changes to current theory; and (g) changing current theory. CC corresponds to g (change in core beliefs) and partly to f (change in peripheral beliefs).	10	11	24	19	64
10	Tyson et al. - Multidimensional framework	TYS	(Tyson et al., 1997)	Conceptual change proceeds through 3 dimensions: (1) ontological, i.e., how the learner perceives the nature of the thing being studied; (2) epistemological, i.e., how the learner perceives his knowledge about the thing being studied; and (3) social/affective, i.e., the motivational/contextual factors necessary to precipitate change.	10	6	20	9	45
11	Dole & Sinatra - Cognitive reconstruction of knowledge model (CRKM)	DOL	(Dole & Sinatra, 1998)	Learner characteristics (i.e., background knowledge, motivational factors) interact with message characteristics (i.e., features of instructional content, such as comprehensibility), leading to a degree of engagement with the new concept. If degree of engagement is high (vs. low), a deeper processing of information occurs, resulting in a possibly strong CC.	9	11	16	4	40
12	Clement - Bridging analogies and anchoring conceptions	CLE	(Clement, 1993)	CC can be induced by bridging analogies between students' conceptions and the scientific theories to be learned.	8	9	25	21	63
13	Nussbaum & Novick - Conceptual conflict and accommodation	NUS	(Nussbaum & Novick, 1982)	CC involves cognitive accommodation produced in 3 phases: (1) exposing learners' alternative frameworks via an "exposing event"; (2) creating conceptual conflict through a "discrepant event"; and (3) encouraging cognitive accommodation, i.e., helping students articulate and elaborate the desired conception.	8	5	24	18	55
14	She - Dual situated learning model (DSLM)	SHE	(She, 2004)	DSLM consists of 6 major stages: (1) examining the target concept's attributes; (2) probing students' misconceptions; (3) analyzing which mental sets students lack; (4) designing dual-situated learning events (DSLE) to create dissonance and provide new mental sets; (5) instructing with DSLE; and (6) application of acquired mental sets to new situations.	7	6	8	-	21
15	Lawson et al. - Learning cycle revised	LAW	(Lawson, Abraham, & Renner, 1989)	CC is produced via a three-phase learning cycle: (1) exploration, i.e., students generate hypotheses and conduct experiments to test them; (2) term introduction, i.e., analysis of experimental results, hypotheses validation and new terms presented; and (3) concept application, i.e., concepts and reasoning patterns reused in other situations.	6	1	11	7	25
16	Givry & Roth, W.-M. - Discursive approach	GIV	(Givry & Roth, 2006)	CC is the evolution of students' ideas through the relationship between three modalities: talk, gestures, and semiotic resources. It consists of (1) evolution in the use of modalities (e.g., use more words instead of deictic gestures); (2) evolution into the same modality; and (3) evolution of the link between modalities (e.g., ratio of time spent in each modality).	5	6	8	4	23
17	White R.T. - Conceptual change and metalearning	WHR	(R. T. White, 1994)	Conceptual change is produced by a major shift in the system of explanations related to a specific phenomenon, whereas conceptual change is the addition of knowledge related to a concept. Conceptual change is more difficult, and requires meta-learning, such as metacognition and resolution of conflict between conceptions.	4	7	16	22	49

18	Sinatra & Pintrich - Intentional conceptual change	SIN	(Sinatra & Pintrich, 2003).	Intentional CC stems from perturbations to learners' existing concepts that lead them to question their current understanding. Deliberate efforts follow to account for those perturbations, consisting of conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge.	4	5	16	2	27
19	Thagard - Branch jumping and tree switching	THA	(Thagard, 1992)	Scientific concepts are divided into treelike hierarchies. CC can be of 9 types of increasing severity. The first 7 are common, e.g. adding a new instance, a new weak rule, a new strong rule, etc. The last 2 are radical: (1) reorganizing hierarchies by "branch jumping"; and (2) "tree switching", i.e., changing the organizing principle of the hierarchical tree.	4	4	15	5	28
20	Novak - Concept maps and Vee heuristics	NOV	(Novak, 2002)	Learner-prepared concept maps result in restructuring of Limited/Inappropriate Propositional Hierarchies (LIPH). Epistemological elements involved in restructuring are shaped as a V. On the left of the V are elements related to our conceptual/theoretical framework; on the right are procedural activities we do that are guided by this framework.	4	3	12	3	22
21	Pines & West - Vine metaphor	P&W	(Pines & West, 1986)	Conceptual change is explained by a vine metaphor: when a learner's spontaneous knowledge (upward growing vine) clashes or conflicts with incongruent formal knowledge (downward growing vine), realizing a conceptual change involves becoming committed to the new set of (formal) ideas that are incongruent with the old ones.	4	2	7	14	27
22	Solomon - Dual Domains	SOL	(Solomon, 1983)	Conceptual change is achieved when we learn to fluently discriminate and move between two contrasting domains of knowledge, the scientific domain and the real-life domain.	4	2	6	11	23
23	Duschl & Gitomer - Portfolio culture	DUS	(Duschl & Gitomer, 1991)	CC occurs via a portfolio culture classroom, the 2 basic and distinguishing characteristics of which are (1) the assessment-based interactions teachers have with students to monitor meaningful learning, and (2) the project orientation of instructional activities and instructional tasks.	3	5	11	11	30
24	Roth, K. J. - Science text approach	ROT	(Roth, 1985)	Science text changes students' schemata via Posner's conditions: (1) pose questions to elicit common misconceptions; (2) emphasize conflict between misconceptions/scientific conceptions; (3) present evidence to challenge misconceptions/provide scientific explanations; and (4) present application questions, i.e., concepts applied to new situations.	3	5	7	6	21
25	Brown - Refocusing of core intuitions	BRO	(Brown, 1993)	CC occurs via bridging instances that build on students' initial intuitions and establish an analogical connection with the target concept. This helps students construct new conscious models of phenomena that contain previously unobserved or unobservable (but imageable) structures or mechanisms.	3	4	14	6	27
26	Caravita & Halldén - Conceptual domains	C&H	(Caravita & Hallden, 1994)	Understanding a scientific concept requires coherence between 3 levels: theoretical concept, theoretical context, empirical context. A similar 3-level organization exists in commonsense knowledge: conceptions, ideological context, and practical context. CC is relating the context of commonsense conceptions to the concepts in scientific theories.	3	4	7	2	16
27	Klopfer et al. - Schema change theory and ideational confrontation	KLO	(Klopfer, Champagne, & Gunstone, 1983)	Conceptual change consists of inducing schema modification via ideational confrontation (i.e., Socratic dialogue), with a schema being a mental structure that consists of concepts and propositions.	3	3	6	3	15
28	Abd-El-Khalick & Akerson - Learning ecology	ABD	(Abd-El-Khalick & Akerson, 2004)	The CC mechanism is the same as in Posner's model, but uses "learning ecology" instead of Posner's "conceptual ecology". Whereas "conceptual ecology" is largely restricted to the cognitive domain, "learning ecology" also includes elements from other domains (e.g., cognitive, affective, contextual, social) that are posited to impact learning.	3	3	5	2	13
29	Mortimer - Conceptual profile change	MOR	(Mortimer, 1995)	Conceptual change consists of conceptual profile change for a concept (e.g., mass), with conceptual profiles being the different modes of seeing and conceptualizing the world used by individuals with regard to the concept.	3	-	5	4	12
30	Osborne & Wittrock - Generative learning model	OSB	(Osborne & Wittrock, 1983)	To comprehend what he is taught, the learner retrieves information from long-term memory and uses information-processing strategies to generate meaning from the incoming information of the experience, to organize it, to code it, and to store it in long-term memory. Motivation (i.e., the drive to construct meaning) plays an important role.	2	5	25	15	47
31	Tytler & Prain - Representational weaving	TYT	(Tytler & Prain, 2010)	CC is learning to use accepted scientific conceptions by representational weaving, i.e., gradually bringing into a more coherent relation appropriate representations (informal thoughts, analogies, anecdotes) related to a phenomenon, such that they are coherent, complete and clear, in order to construct convincing explanatory narratives.	2	2	5	2	11
32	Limon - Meaningful cognitive conflict	LIM	(Limon, 2001)	The starting point of conceptual change is provoking a meaningful cognitive conflict. Meaningfulness of conflict depends on variables related to the learner, the social context and the teacher.	2	2	4	8	16
33	Karplus & Thier - Learning cycle	KAR	(Karplus & Thier, 1967)	The learning cycle consists of 3 instructional phases: (1) exploration, i.e., experience of new ideas/material, raising questions and creating mental disequilibrium; (2) concept introduction, i.e., social transmission of new concepts, aiding self-regulation; and (3) concept application, i.e., familiarization by applying concepts to additional situations.	2	2	3	-	7
34	Lombardi et al. - Plausibility judgments in conceptual change (PJCC)	LOM	(Lombardi, Nussbaum, & Sinatra, 2016)	CC is a shift in plausibility from incorrect, existing background knowledge toward the novel, scientific explanation. It occurs in 3 steps: (1) pre-processing of source validity; (2) plausibility judgment of the novel explanation; and (3) if plausibility of new explanation > plausibility of background, there is a shift toward the scientific explanation.	2	2	3	-	7
35	Klein - Writing operations and science learning	KLE	(Klein, 2004)	Scientific explanations are constructed through writing, a modality that favours reaching and resolving contradictions and impasses (more than verbal). This occurs through 3 kinds of cognitive processes (i.e., perceptual search & controlled retrieval, automatic retrieval, problem solving) and metacognitive processes (e.g., goal-setting).	2	2	2	1	7
36	Potvin - Conceptual prevalence	POT	(Potvin, 2013)	Conceptual change can be produced via three steps: (1) make the scientific conception available to the learner; (2) install inhibitive stop signs for misconceptions; and (3) using automaticity, ensure the continued prevalence of the scientific conception at the expense of the misconception.	2	2	2	1	7

37	Dykstra et al. - Differentiation, class extension and reconceptualization	DYK	(Dykstra, Boyle, & Monarch, 1992)	CC can occur via (1) differentiation, i.e., new concepts emerge from existing, more general concepts; (2) class extension, i.e., existing concepts considered different are found to be cases of one subsuming concept; and (3) reconceptualization, i.e., a significant change occurs in the nature of, and relationship between, concepts.	2	1	12	4	19
38	Tiberghien - Theoretical conceptual change	TIB	(Tiberghien, 1994)	CC can be of two types: (1) semantic CC, which corresponds to a deep modification in the structuring of the field of objects and events, but where the theory is not radically changed; and (2) theoretical CC, which corresponds to a change at the level of theory, and in particular, with respect to causality.	1	3	8	3	15
39	Bliss & Ogborn - Piagetian systems of reasoning	BLI	(Bliss & Ogborn, 1994)	Reasoning about force and motion starts from primitive elements (i.e., actions) that evolve into schemes (i.e., sets of actions). Some schemes are rules, i.e., schemes which express general constraints. The last element is prototypes, i.e., complexes of actions/schemes/rules forming a pattern of behaviour used to interpret motions and forces.	1	3	5	-	9
40	Cobern - Worldview theory	COB (White)	(Cobern, 1996)	Worldview provides the environment for (1) reasoning, i.e., the capacity for rational thought, which operates via (2) thinking, which produces (3) comprehension of a new concept that is assessed for plausibility via (4) knowing, i.e., a metaphysical process that leads to (5) apprehension, i.e., accepting as true or valid the newly comprehended concept.	1	2	4	2	9
41	White B.Y. - ThinkerTools (computer microworlds)	WHB	(B. Y. White, 1993)	Via problem solving and experimentation with a series of computer microworlds (i.e., interactive simulations and modelling tools called ThinkerTools), learners construct causal models that embody the principles of Newtonian mechanics.	1	2	3	4	10
42	Roschelle - Distributed encoding	ROS	(Roschelle, 1991)	CC is an organic growth in students' knowledge that occurs by transforming students' (1) registrations, i.e., features that are perceived, labelled and selected for attention; (2) qualitative cases, i.e., schemata for qualitative problem solving; and (3) use of p-prims, i.e., generative metaphors used to construct explanations.	1	2	3	-	6
43	Banet & Nunez - Attractive and surprising activities	BAN	(Banet & Núñez, 1997)	CC can be induced by three steps: (1) initiation of students' ideas; (2) restructuring of ideas; and (3) application and review of new ideas. The sequence centres on attractive or surprising activities to capture students' attention.	1	2	2	-	5
44	Wang & Andre - Conceptual change text (CCT)	WAN	(Wang & Andre, 1991)	The CCT consists of (1) determining typical student misconceptions about a topic; (2) eliciting students' misconceptions via examples that lead them to make predictions; (3) providing evidence that their misconceptions are wrong; (4) presenting scientifically accepted ideas; and (5) providing opportunities to apply scientifically correct ideas.	1	2	2	-	5
45	Alsop & Watts - Four lenses CC model	ALS	(Alsop & Watts, 1997)	Extension of Posner's original CCM to include 3 dimensions in addition to the cognitive: (1) affective, i.e., how students' interests influence their attention/effort; (2) conative, i.e., the extent to which knowledge can be made practically applicable to students' lives; and (3) learners' self-esteem, i.e., image, confidence, autonomy.	1	1	2	-	4

37	Dykstra et al. - Differentiation, class extension and reconceptualization	DYK	(Dykstra, Boyle, & Monarch, 1992)	CC can occur via (1) differentiation, i.e., new concepts emerge from existing, more general concepts; (2) class extension, i.e., existing concepts considered different are found to be cases of one subsuming concept; and (3) reconceptualization, i.e., a significant change occurs in the nature of, and relationship between, concepts.	2	1	12	4	19
38	Tiberghien - Theoretical conceptual change	TIB	(Tiberghien, 1994)	CC can be of two types: (1) semantic CC, which corresponds to a deep modification in the structuring of the field of objects and events, but where the theory is not radically changed; and (2) theoretical CC, which corresponds to a change at the level of theory, and in particular, with respect to causality.	1	3	8	3	15
39	Bliss & Ogborn - Piagetian systems of reasoning	BLI	(Bliss & Ogborn, 1994)	Reasoning about force and motion starts from primitive elements (i.e., actions) that evolve into schemes (i.e., sets of actions). Some schemes are rules, i.e., schemes which express general constraints. The last element is prototypes, i.e., complexes of actions/schemes/rules forming a pattern of behaviour used to interpret motions and forces.	1	3	5	-	9
40	Cobern - Worldview theory	COB (White)	(Cobern, 1996)	Worldview provides the environment for (1) reasoning, i.e., the capacity for rational thought, which operates via (2) thinking, which produces (3) comprehension of a new concept that is assessed for plausibility via (4) knowing, i.e., a metaphysical process that leads to (5) apprehension, i.e., accepting as true or valid the newly comprehended concept.	1	2	4	2	9
41	White B.Y. - ThinkerTools (computer microworlds)	WHB	(B. Y. White, 1993)	Via problem solving and experimentation with a series of computer microworlds (i.e., interactive simulations and modelling tools called ThinkerTools), learners construct causal models that embody the principles of Newtonian mechanics.	1	2	3	4	10
42	Roschelle - Distributed encoding	ROS	(Roschelle, 1991)	CC is an organic growth in students' knowledge that occurs by transforming students' (1) registrations, i.e., features that are perceived, labelled and selected for attention; (2) qualitative cases, i.e., schemata for qualitative problem solving; and (3) use of p-prims, i.e., generative metaphors used to construct explanations.	1	2	3	-	6
43	Banet & Nunez - Attractive and surprising activities	BAN	(Banet & Núñez, 1997)	CC can be induced by three steps: (1) initiation of students' ideas; (2) restructuring of ideas; and (3) application and review of new ideas. The sequence centres on attractive or surprising activities to capture students' attention.	1	2	2	-	5
44	Wang & Andre - Conceptual change text (CCT)	WAN	(Wang & Andre, 1991)	The CCT consists of (1) determining typical student misconceptions about a topic; (2) eliciting students' misconceptions via examples that lead them to make predictions; (3) providing evidence that their misconceptions are wrong; (4) presenting scientifically accepted ideas; and (5) providing opportunities to apply scientifically correct ideas.	1	2	2	-	5
45	Alsop & Watts - Four lenses CC model	ALS	(Alsop & Watts, 1997)	Extension of Posner's original CCM to include 3 dimensions in addition to the cognitive: (1) affective, i.e., how students' interests influence their attention/effort; (2) conative, i.e., the extent to which knowledge can be made practically applicable to students' lives; and (3) learners' self-esteem, i.e., image, confidence, autonomy.	1	1	2	-	4

55	Ohlsson - Resubsumption	OHL	(Ohlsson, 2009)	CC occurs in 3 phases: (1) bisociation, i.e., recognition that theory A originally formed for domain A also applies to target domain B; (2) competitive evaluation, i.e., estimates of the cognitive utility of the now two competing theories in domain B; and (3) resubsumption, i.e., theory A (more useful) becomes the dominant theory in domain B.	1	-	4	-	5
56	Gilbert et al. - Taxonomy of children's science and CC	GIL	(Gilbert, Osborne, & Fensham, 1982)	A taxonomy of genesis of children's science (i.e., alternative conceptions) is proposed (e.g., everyday language, egocentric viewpoint, etc.). It has consequences for CC, resulting in 5 possible outcomes after science teaching, that range from the "undisturbed children's science outcome" to the "unified scientific outcome".	1	-	3	3	7
57	Tsai - Conflict maps	TSA	(Tsai, 2000)	CC is produced by conflict maps, the sequence of which is: (1) discrepant event inducing dissatisfaction; (2) teaching of the target scientific concept; (3) critical event and explanation, i.e., experiment demonstrating target concept; (4) teaching of conceptual supports for the target concept; and (5) creating supporting perceptions (e.g., analogies).	1	-	3	3	7
58	Demastes et al. - Patterns of conceptual change	DEM	(Demastes, Good, & Peebles, 1996)	CC occurs through 4 patterns: (1) cascade, i.e., a sequence of conceptual changes; (2) wholesale, i.e., prior conception completely discarded for a new one; (3) incremental, i.e., use of a new term within a previously constructed explanation; and (4) dual constructions, i.e., a second competing conception is constructed and both are applied.	1	-	1	2	4
59	Talanquer - Commonsense	TAL	(Talanquer, 2006)	Alternative conceptions in chemistry are underlaid by a commonsense explanatory framework that relies on several empirical assumptions and reasoning heuristics. Producing conceptual change requires recognition and characterization of students' alternative conceptions according to this framework.	1	-	1	1	3
60	Schwedes & Schmidt - Change in conceptual hard core	S&S	(Schwedes & Schmidt, 1992)	Upon the presentation of counter-evidence that conflicts with a learner's initial theory, the learner's explanation-seeking curiosity is aroused and he will be driven to construct a new theory that will quench his curiosity.	1	-	1	-	2
61	Spiro et al. - Multiple analogies	SPI	(Spiro, Feltovich, Coulson, & Anderson, 1989)	Additional analogies promote CC via 8 functions: 1. supplementation (with a new analogy); 2. correction (with a new analogy); 3. alteration (of an earlier analogy); 4. enhancement (of an earlier analogy); 5. magnification (or elaboration); 6. perspective shift; 7. competition; and 8. sequential collocation (analogies explain segments of a phenomenon).	1	-	1	-	2
62	Galili & Hazan - Facets and schemes of knowledge	G&H	(Galili & Hazan, 2000)	Conceptual change is the spread and alteration of facets and schemes of knowledge. Facets are cognitive units of reasoning applied by students when addressing particular situations, whereas schemes are a more inclusive unit of a higher level of abstraction that represent core explanatory patterns.	1	-	-	-	1
63	Duit et al. - Discourse pattern changes	DUI	(Duit, Goldberg, & Niedderer, 1992)	Conceptual change is evident from changes in the discourse of groups and individuals. Concepts can therefore be viewed as the patterns in the language employed by students to describe and explain their science-related experiences, and conceptual change is the change in these descriptions and explanations.	-	2	2	1	5
64	Dekkers & Thijs - Enhancing of detail model	DEK	(Dekkers & Thijs, 1998)	Conceptual change in mechanics occurs when students learn to distinguish two quantities that were initially mixed up (e.g., speed and acceleration).	-	2	2	-	4
65	Gregoire - Cognitive-affective model of CC (CAMCC)	GRE	(Gregoire, 2003)	Cognitive (e.g., background knowledge) and motivational (e.g., self-efficacy, stress appraisal) factors interact with message characteristics. If this interaction is positive, the message is perceived as challenging and an intention of approaching it is created, thus leading to accommodation or true conceptual change.	-	2	2	-	4
66	Tirosh & Stavy - Intuitive rules	T&S	(Tirosh & Stavy, 1999)	CC is induced when students realize the inapplicability of their intuitive rules, such as Same A - Same B or More A - More B.	-	1	2	5	8
67	Chan et al. - Knowledge-processing activity	CHA	(Chan, Burtis, & Bereiter, 1997)	Conceptual change is correlated with the level of knowledge-processing activity. Higher levels of processing (called knowledge building), which involve treating new information as something problematic that needs to be explained, exert more effect on conceptual gain than lower levels (e.g., subassimilation, assimilation).	-	1	2	4	7
68	Glasson & Lalik - Language oriented learning cycle (LOLC)	GLA	(Glasson & Lalik, 1993)	The LOLC consists of 3 phases: (1) exploration, i.e., learners experience cognitive disequilibrium via concrete materials and experiences; (2) clarification, i.e., learners build new knowledge to account for their observations via stimulating activities arousing their curiosity; and (3) elaboration, i.e., learners engage in divergent problem-solving.	-	1	2	-	3
69	Niedderer & Schecker - Cognitive system	NIE	(Niedderer & Schecker, 1992)	The mind consists of a cognitive system which contains cognitive elements (e.g., concepts, schemes, frames of thinking) and cognitive processes operating on them. Various possible CC ways exist: developing new cognitive elements, employing existing cognitive elements in new context areas, developing new cognitive processes, etc.	-	1	2	-	3
70	Kelly & Green - Sociocultural perspective	KEL	(Kelly & Green, 1998)	An individual's conceptual ecology (CE) is interdependent on the group's CE. When a frame clash occurs (i.e., conflict), interactions between individual's and group's CE can lead to initiation of individuals to the group's normative view (individual CC) or to the normative view brought to the group by a social mediator like a teacher (group CC).	-	1	1	3	5
71	Blank - Metacognitive Learning Cycle	BLA	(Blank, 2000)	Conceptual change is produced via 4 phases: (1) concept assessment, where students reflect on their ideas; (2) concept exploration, where students explore phenomena; (3) concept introduction, where the main concept is presented; and (4) concept application in other examples. Students reflect on the status of their ideas throughout.	-	1	1	-	2
72	Dawson - Conceptual mediation	DAW	(Dawson, 2014)	CC is produced by conceptual mediation, the sequence of which is: (1) identify students' pre-existing view (pretest); (2) teach the scientific view and make students practise using the new view repeatedly; (3) discuss pretest examples from both viewpoints and find differences; and (4) make students practise only the new view repeatedly.	-	1	1	-	2
73	Neale et al. - Social constructivist model	NEA	(Neale, Smith, & Johnson, 1990)	Conceptual change can be induced by a three-step teaching sequence: 1) diagnosing students' conceptions; 2) contradicting students' conceptions via discrepant events and debate; and 3) constructing scientific conceptions via discussion, application and modelling of cognitive processes.	-	1	1	-	2

74	Pauen - Causes and effects of changes (CEC) model	PAU	(Pauen, 1999)	CC is learning to distinguish between ontological categories of material entities via 3 dimensions: (1) causality, i.e., knowledge of causes of specific changes that various classes of entities perform; (2) functionality, i.e., knowledge of purposes of such changes; and (3) predictability, i.e., knowledge of likelihood of occurrence of such changes.	-	1	1	-	2
75	Alexander - Model of domain learning (MDL)	ALE	(Alexander, 1998)	CC is developing literacy in a domain in 3 stages: (1) acclimation, i.e., limited knowledge, use of general strategies, little personal investment; (2) competence, i.e., platform of relevant knowledge, better use of strategies, enhanced interest; and (3) proficiency, i.e., rich cohesive body of knowledge, well-honed strategic repertoire, abiding interest and investment.	-	-	1	2	3
76	Prawat - Knowledge organization and reflective awareness	PRA	(Prawat, 1989)	Two factors foster CC: (1) organizational, i.e., concepts are represented as nodes within a system and are interconnected via associative links, thus teaching must connect elements of naive and scientific views; and (2) amount of reflective awareness, i.e., learners' ability to access relevant strategies in new learning situations.	-	-	1	1	2
77	Ali - Preconception activation strategies	ALI	(Ali, 1990)	Conceptual change can be produced in 5 steps: 1. search for their own preconceptions; 2. compare and contrast their own preconceptions with the new information; 3. formulate a new conception, based on the previous step; 4. apply the new conception; and 5. evaluate the new conception.	-	-	1	-	1
78	Anders & Commeyras - Feminist perspective	AND	(Anders & Commeyras, 1998)	Relationship between gender and science learning in mixed-gender contexts is crucial. The major role of inquiry on CC within this perspective involves deconstructing normative constructs such as reason, science and objectivity across genders. The social roles and power relations across genders must also be examined.	-	-	1	-	1
79	Carey - Quinian bootstrapping	CA1	(Carey, 2009)	Quinian bootstrapping occurs in 2 phases: (1) establishing new mental symbols initially interpreted in terms of concepts already available (placeholders); and (2) modelling a phenomenon in terms of the set of interrelated symbols in the placeholder structure, leading to explicit representation and the capacity to formulate a new concept.	-	-	1	-	1
80	Furberg & Arnseth - Sociocultural perspective	FUR	(Furberg & Arnseth, 2009)	CC consists of students' meaning making via collaborative learning activities. The 4 central aspects of meaning making are: (a) students' use of resources in problematizing; (b) multiple aspects of teacher intervention; (c) changes in interactional accomplishments; and (d) institutional aspect of meaning making.	-	-	1	-	1
81	Giordan & de Vecchi - Allosteric learning model	GIO	(Giordan & DeVecchi, 1987)	Conceptual change consists of the transformation of initial conceptions into more functional conceptions, via simultaneous deconstructions and reconstructions that are analogous to changes in the conformation of the allosteric protein. An optimal pedagogical learning environment is necessary for this transformation to occur.	-	-	1	-	1
82	Miyake - Conceptual change through collaboration	MIY	(Miyake, 2008)	Conceptual change occurs via collaboration: solutions to problems evolve in a divergent group of learners. Solutions are then sorted to integrate those that are most relevant and promising into a schema or some abstracted representation of the solution, which becomes a solid source for further changing the concepts into scientific ones.	-	-	1	-	1
83	Myers & Alvermann - Critical postmodernist perspective	MYE	(Myers & Alvermann, 1998)	This perspective embraces the desire to reveal the codes of power within students' relations and student-teacher relations, and the discourses of oppression in order to enable all participants to be emancipated, i.e., contest being made into the objects of texts and truths and negotiate new subjectivities (i.e., scientific conceptions) and relationships.	-	-	1	-	1
84	Schwitzgebel - Children's theories and drive to explain	SCH	(Schwitzgebel, 1999)	Upon the presentation of counter-evidence that conflicts with a learner's initial theory, the learner's explanation-seeking curiosity is aroused and he will be driven to construct a new theory that will quench his curiosity.	-	-	1	-	1
85	Tao & Gunstone - Context-independent and stable conceptual change	TAO	(Tao & Gunstone, 1999)	Conceptual change proceeds in 2 phases: a context-dependent and unstable phase, where students vacillate between alternative and scientific conceptions across contexts, and a context-independent and stable phase, where students perceive the commonalities and accept the generality of scientific conceptions across contexts.	-	-	1	-	1
86	Chinn & Samarapungavan - Resubsumption multiple routes	C&S	(Chinn & Samarapungavan, 2008)	CC can occur via Ohlsson's resubsumption or via multiple routes that are derivatives of it: (1) resubsumption + substantial modifications of conceptual system B before or after resubsumption; (2) revision of a single conceptual system instead of resubsumption; (3) invention of new conceptions; and (4) reconceptualizing a domain; etc.	-	-	-	1	1

than half (136) of all (245) articles explicitly present Posner's contribution as a CC model. In second place comes Vosniadou's; in third comes Chi's; etc. The first seven models (POS; VOS; CHI; HEW; DIS; CA2; PIN) have attracted more explicit mentions than the rest of the CC models taken together.

Contrasting with these results, the analysis of the implicit mentions (Figure 5) is very interesting because the hierarchy is somewhat different. Driver's (DRI) contribution is now in first place, and while some of the hierarchy remains the same, Chi's contribution tumbles to 13th position and Posner's to 10th, while White's (WHR) and Clement's (CLE) contributions have climbed into the top seven. We believe that these observations suggest that some influences (DRI, WHR, CLE) in the conceptual change field may be of capital importance, while not necessarily being explicitly presented as models by the authors. Others (POS, CHI) are almost always considered as models when mentioned, so much so that authors seem to avoid presenting them as non-model contributions.

Figure 5 shows a smaller number of models being mentioned than does Figure 3. We believe this to be normal since it is more difficult to identify a clear target of reference in implicit mentions, unless very well-known or exclusive components of certain models are discussed, which happens less often and is more restrictive.

Figure 7 shows instances in which positive value judgements accompanied mentions. In this case, the quantitative superiority of Posner's CC model appears to be even clearer than in the previous figures (65 favourable position statements). It 'dominates' Vosniadou's (VOS) model with twice the approval, and has three times the number of support that CHI's has obtained. Similar to our previous finding, half of the favourable position statements are concentrated in the first six models (this time: POS; VOS; CHI; HEW; PIN; DIS) and the rest of the CC models share the other half.

Empirical articles (total = 186) have also provided experimentally based confirmation of the value of certain models, or of parts or consequences of them. Figure 10 provides the number of articles that show such confirmation. In this case, the quantitative domination of POS is not as strong (but remains indisputable), but the presented order is not very different from that observed in earlier analyses (POS; VOS; HEW; CHI; PIN; DIS; etc.).

In light of these observations, we believe that, even though we have recorded a rather large number of models, we can identify reasonably clear tendencies about the ones receiving the most positive support (also see Table 3) from our corpus. These models are POS, VOS, CHI, HEW, PIN, DIS, and maybe CLE and CA2. However, it might be unfair to disqualify as major influences the contributions of DRI and WHR, even though they are not always explicitly identified as models in our corpus.

Of course, the shortlists presented in this discussion are necessarily biased by seniority. Indeed, older models have better chances of garnering most of the accumulated positive support; not only because they might have acted as pioneers and are thus necessarily inspirational, but also because they have simply had more opportunities to accumulate references, having been around for longer. Indeed, for example, very recent propositions (e.g., the dynamic model of conceptual change [DMCC] (Nadelson et al., 2018), have not yet gained any support from our corpus despite their obvious qualities. Therefore, our 'historic' analysis of support is unable so far to enlighten recent trends. This is why we have conducted an additional analysis of the number of supporting articles (for all kings of support) *per year*. Thus an alternative version of Table 3 appears in supplementary materials under 'Additional Table of models (per year)' and shows that the 'top 10' has not seen major changes. Only two models (SHE and DOL) have made their entry, while C&B and CA2 have been excluded, while not very far (12^{th} and 13^{th}). VOS is now the 1^{st} model and POS gets second place in this correction.

Before getting interested in temporal trajectories, let us have a look at the 'negative' support models have received.

Critiques and refutations

Of course, articles from our corpus do not always refer to CC models in noncritical ways. Figure 9 presents unfavourable position statements, and we find in the top seven of the list many of the models that have also received positive support (POS, VOS, CHI, CA2, PIN). This result is rather unsurprising since it could be considered normal that the most popular models should also be the ones that are more frequently observed and analysed by researchers. However, it is more surprising to see the extent to which diSessa's (DIS) perspective (usually ranking 4th or 6th, and here rising to reach 2nd position) has been the target of much negative criticism. Here, we can hypothesise some possible causes: (a) it is considered defective or is misunderstood, (b) it is emblematic of the top models as an adversary, (c) it is divergent or ground-breaking (and therefore counter to mainstream CC), or (d) it mainly focuses on physics, which restricts the amount of general support it can get. We also notice that Nussbaum's very early contribution (NUS) has suffered more critiques than its precedent approval rankings (11th, 9th and 19th) might have led us to presume, making a first appearance in the 6th position. In this case, however, we believe that the explanation is easier to find: this model might be considered too simple (discrepant event + transmissive teaching), fitting less clearly in the general constructivist frame, and/or it may have been rapidly supplanted by Posner's model, which can be seen as an upgrade to Nussbaum's model.

We can then notice similar observations, but with *empirical refutations* (Figure 12). In this list, which does not constitute an argument as strong as the previous ones because of its smaller numbers, we can still notice the presence of NUS (5th) and other models that were not as often among the most supported ones (OSB, KLO). Also noticeable is the presence of Chi's model (2nd place) among the top six, as well as diSessa's drop to 8th position, tying with many others, which might suggest that the unfavourable position statements that had targeted this model might not be often empirically founded.

Trends

When examining Figures 4, 6, 8, and 12 (and others in supplementary materials), we can suggest a general trend for the different types of support that our corpus has provided throughout the history of the field. We can say that the 1980 s saw mostly discussions about CC models and, possibly, about the early propositions (without necessarily presenting them as models (Figure 6)). Then, in the '90 s, authors began to issue many more value judgements about them (Figure 8). The '90 s also saw a gradual rise in empirical confirmation (Figure 11) of the value of such models, and the 2000 s recorded the largest number of experimental confirmations or refutations (as well as supports of all kinds). We therefore believe that the field has undergone a rather healthy progression through this sequence of events.

Our timeline figures often also show important peaks in the mid-2000 s (for mentions, for example), suggesting that a great deal of CC activity occurred during this period, and that it is not impossible that the field had then reached somewhat of a 'golden age'. This suggestion, however, will have to be confirmed in the future, with the benefit of temporal distance. These peaks could also have been artificially boosted by a few articles that exhaustively presented the influences of the field through more references than usual, sometimes within reviews of literature [e.g., Palmer (2005)].

But still, it does not appear over-stated to suggest that the conceptual change field has seen better days, especially since other review initiatives have also recorded a decline. A few hypotheses can be formulated to explain this state of fact. The first one concerns the focus of most CC models on *individual* learning. In recent years, the CCM and associated constructivist theories might have been eclipsed by more social and situated theories of learning. These newer theories look into social processes, discourse, and meaning, rather than individual conceptions. The CCM might not have been able to keep up with such changes in learning theory, and authors (and possibly whole research cultures, like the francophone world) might have sometimes chosen to avoid or even reject it. Another possibility could be attributable to the complexity of the conceptual change phenomena. It is indeed possible that research techniques are still unable to grasp the integrality of such a phenomenon, and allow only rough conclusions. Thus researchers could remain interested in conceptual change, but might also be a bit disappointed or confused by the diversity and ill-convergence of available prescriptions. Of course, it is today widely accepted that misconceptions have to be taken into account in teaching (and this is an important and concrete result of the field), but interest in a topic also has to be cultivated by new and converging results in order to avoid ceiling effect or declines in adherence. Finally, a third possible explanation for the apparent decline could be that research activities traditionally identified to conceptual change might have moved into- or closer to- other fields, or use different labels. For example, recent neuroeducational research efforts have seen frameworks and concepts from the educational and neuroscientific worlds exchanged, and sometimes mixed or reformulated. It is thus possible that CC is experiencing some sort of (at least partial or sectorial) mutation that prevents an easy identification of all relevant research projects with traditional keywords.

Relative support

Since our timeline figures present absolute numbers of articles, they do not necessarily allow us to easily understand the temporal tendencies of the *relative* support that each model has received. We thus suggest referring to the figure presented in supplementary materials [named 'Explicit mentions – time (percentages)']. It allows us to see that many models that appeared in the late '80 s but mostly in the early '90 s are often those that are most frequently mentioned today as CC models (VOS; DIS; CHI; PIN; C&B and DOL (and maybe CLE)). On the other hand, Posners' (POS) and Hewson's (HEW) models (and also maybe Nussbaum's [NUS]), for instance, after having occupied most of the field for many years, are in relative decline today (at least in terms of *explicit mentions*), while still being relatively popular. Similar observations could also be made for other kinds of support (not presented here in relative mode). These general results are not too distant from the lists of important models that many articles present in their literature reviews (Amin et al., 2014; Vosniadou, 2008b). Indeed, we see clear similitudes with the more systematic reviews of the past, especially for older or most popular models (J.-W. Lin et al., 2016; Tyson et al., 1997). However, the reasons why these models appear in such repertoires is not always clear. Are they usually mentioned or presented because they have been much cited or empirically confirmed in the past? Have these particular models been integrated to articles because they are worthy opponents that best illustrate the typical tensions that are inherent to the field? (*e.g., knowledge as theory vs. knowledge in pieces*) Do we write about them because they are pioneers or because they are obsolete, or because their popularity or credibility has been rising or falling? How do we know how important or dominant they are in the eyes of the educational research community (authors and readers of research journals)? Are the non-emblematic models as convincing as the main ones?

For the moment, we believe that such question remain largely unanswered. However, the present review study now provides quantitative arguments to support the consideration of most models. At the top of the 'explicit mentions' figure, we can also record the appearance of many weakly (so far) supported models that do not seem to be able to impose themselves, or whose existence in the field has been short-lived. However, these propositions should not necessarily be discarded as not promising. We believe that the field might benefit in the future from such variety.

Of course, we should be very cautious about making projections on the basis of recent indexations, since they are less numerous, but we certainly look forward to seeing how trends will unfold in the future.

Limitations

While carrying out this research, we have made many methodological choices that necessarily made us partially blind to certain aspects that might be considered important in the field of conceptual change research. For example, the database research algorithm we used certainly made us undermine the importance of the support that some models have received over the years. For example, Mortimer's model [MOR], which we recorded as a legitimate model of conceptual change, is not always identified by authors as a typical 'conceptual change model,' but perhaps more often given the label of 'conceptual profile' change. It is therefore almost certain that we did not record all the support that might have been given to it in the science education literature.

The final choice to keep all the articles of the most 'populated' journals also probably made us undermine the importance of some models that are more typical of certain scientific disciplines, such as Talanquer's model [TAL: 'commonsense' model], for example, for which we are almost certain to have failed to record an accurate amount of support, since it probably has been mostly published in- and supported by articles in- *chemistry* education journals.

Also, other than through the 'Learning and Instruction' journal, our analysis might not have benefited enough from the input of psychologists who prefer to publish their work in less education-oriented, more psychology-focused journals. We believe, for instance, that if we had selected more psychology journals, certain very rich and interesting models such as Ohlsson's [OHL] or Carey's [CA1 and CA2] might have earned more support or criticism. It is in fact not so uncommon to see special issues about conceptual change in journals that we did not select in the end [e.g., the 'Conceptual Change and its models' special issue, published in 2014, in *Science and Education* (Koponen, 2014)]. In addition, other important concepts in the field of psychology that clearly have the potential to enrich the field of conceptual change research may have eluded us, such as *error correction* (Glaser, 1990), *prevalence* (Taylor & Kowalski, 2004), *dual-process theory* (Evans, 2003), to name a few.

Our decision to limit ourselves to published articles could also have prevented us from recording important support that might appear in books, collective works [such as Guzetti and Hynd (1998)] or handbooks, such as the 2008 *Handbook on Conceptual Change* (Vosniadou, 2008b), for example. However, we stand by our decision, because otherwise, the self-citation and general quality issue would have complicated our task, since strong peer-reviewed processes are more often secured in well-established journals.

We also have to live with the consequences of the choice we made to concentrate on models instead of, for instance, *authors, ideologies, epistemologies*, or the mere *roots* of the field of conceptual change research. This choice unfortunately forced us to unfairly reduce authors to single (and oversimplified) contributions, while their contribution is usually much broader and richer. Concentrating on models also prevented us from offering an analysis of the support that is given to certain ideas fundamental to the field, such as *cognitive conflict, ontological recategorisation*, or the *coexistence* (or not) of misconceptions, for example. All these ideas are often shared by more than one model. Therefore, their importance in our study cannot be understood because it is fragmented into many items. For example, VOS and CHI (2nd and 3rd in our general hierarchy [Table 3]), while different, share many things in common that have to do with ontological recategorisation. If put together, it is not impossible that the total support they received had been higher in the list.

In the end, we can only understand our review study as a particular and connoted peek into the history of conceptual change. We hope that systematic and complementary efforts that would be similar to ours will be able to reproduce or complete our results while making different or convergent methodological choices.

Contribution to the field

We hope that our review will help researchers and graduate students *situate* their own work within- or out of- the conceptual change field, see where it goes and possibly where it could or should be going/doing. Looking at our inventory of models (Table 3), they might evaluate the conformity of their commitments with the already available models and rapidly see if their own ideas have already been formulated in the past or if similar ones gotten support. They can also assess their own situation and beliefs as researchers or teachers in the actual trends and tendencies; they can identify blind spots and attempt to imagine what kind of research could now bring new insights. They can also see the general tendencies through all the figures that deploy in time lines and, if they are defenders (or developers) of one of the recorded models, evaluate the support that their 'favourite' proposition got from the community.

Our contribution could also help academics to reflect on the field itself and propose constructive critiques of it. In the apparent actual erosion, it nevertheless remains very active (in absolute terms) and many of its participants and members apparently judge its contribution to the educational field to be important and still possibly promising. The plethora of models and the convergence of most support on very few of them (six or seven) could be interpreted both as a strength and as a weakness.

But still: why is there an apparent need to propose new models, which sometimes do not diverge a lot from the already existing ones? Is it a 'research industry' effect, or a true conviction that the field crucially needs to survive, is renewed and remain fruitful for the sake of science education/learning?

Another question: can the recorded happening of new- and diversification of- CC models necessarily be seen as progress or as a supplementary chance to eventually 'get it right'? We believe not, unless considerably more comparative or refutational research efforts eventually be published. Clearly, it is not impossible that we might be in need of some type of filtering, even within the set of the few most important models. Minimal convergence is essential to the future of a field, but does not appear to be witnessed right now in the conceptual change domain. We thus call for more comparative research efforts, which confront not only the effects of CC models/propositions with trivial or ill-defined teaching interventions, but also with each other. This way might we be able to converge. Indeed, what would someone think of a field, say, like physics, if eighty-six models of movement were simultaneously proposed without providing clear possibilities to discriminate between them?

We also believe that the observed decline could possibly be attributable to an excessive simplicity of the field's mainly used constructs. For example, very early in the history of the CC research programme, the idea of 'change' (or 'exchange') has been criticised. Even if considerable efforts were made to understand students' conception not as constraints, but rather as instruments that have to be used in so-called 'reconstructional' efforts (Kattmann, 2008), we can hardly say that this misunderstanding has definitely been resolved. Indeed, most newcomers in the CC field rapidly have to learn to inhibit their first inclination to think that misconceptions must be *replaced*.

The important idea of 'conflict' also has had its share of critiques. Such conflicts are seen by experts as 'cognitive' and 'constructive', and thus should not be understood, in a constructivist framework, as a way to discredit individual ideas or the persons that hold them. But teachers sometimes have a hard time avoiding this. Finally, the idea of 'conception' can also produce negative effects, by suggesting that student's ideas are monolithic, and can be completely captured by using simple instruments like questionnaires. On the contrary, research shows that they are ever dynamic, fragile and changing.

Such 'conceptual' obstacles are not negligible, and it is not impossible that the field should reflect on the best ways to integrate, through its fundamental constructs, ideas such as *coexistence, flexibility, deliberation, context, affect, prevalence, duration*, as well as *social* and *cultural* dimensions. Efforts are being made in this direction; however, they might sometimes lack a bit of marketing skills. For the moment, a lot of people still see the CC phenomenon essentially as an *individual* and *instantaneous* insight that happens in a presumably rational learner's mind, after a single best intervention available. For those who appreciate a bit more subtlety, the general idea of *conceptual change*, which paradoxically comes with its share of *common sense* meanings, might appear insufficient to address real and complex educational problems. We thus suggest that researchers be more attentive to such issues in the future, and adjust their messages accordingly, especially when addressing them to teachers.

Next steps

We believe that this review study could be the first step of a larger research programme in which, for example, instead of merely counting the number of empirical confirmations or refutations, we could strive to evaluate the strength of given items of support, through a meta-analytical study.

It could also be interesting to dissect all the models considered herein in order to label them according to their characteristics and suppositions. We believe that it would be a worthwhile undertaking to assess the importance of concepts that are smaller than models but might constitute more fundamental ideas in the field, while contrasting with the results presented here. Questions such as: 'What support does the idea of *conceptual conflict* receive from the literature?', and 'Is this type of support increasing or not?' would be worth investigating, for example.

Conclusion

In this review study, we analysed 245 articles in order to evaluate the support provided by the literature for each of the recorded CC models throughout the history of the field (1980-onward). This analysis has given us a glimpse of the relative importance of all CC models and of their possible trajectories as credible possibilities in the eyes of authors. The results suggest that most of the support usually centres around six or seven models, while the remainder usually share the rest. These models are, in decreasing order of their recorded support: Posner et al.'s *General model of conceptual change* (1982), Vosniadou's *Mental model modification* (1994), Chi's *Ontological category shift* (1994), almost tying with Hewson's *Conceptual capture and conceptual exchange* (1980), Pintrich et al.'s *Beyond cold conceptual change* (1993), diSessa's *P-prim reorganisation* (1993), and Driver et al.'s *Students' epistemological reasoning categorisation* (1996). Among these models, those developed in the early 1990 s seem to be gaining ground over the ones that appeared in the '80 s.

However, the great number of CC models that have been proposed might generate confusion and could possibly impede synthesis and the clarity of pedagogical/didactic prescriptions. We therefore believe that greater effort could be made to find the constants that exist across these models, and to highlight their components that have been the subject of the best or most frequent confirmations or refutations. It is important to remember that students and teachers are still waiting for realistic, more effective recommendations.

Our analysis allowed us to offer a hierarchical list. The content and order of the elements constituting this list remain disputable. But considering the methodological choices we made and have described in this article, and keeping in mind that distraction errors are possible and that smaller but sometimes difficult choices (not necessarily explained here) had to be made on a day-to-day basis, we believe that we could not have developed a fundamentally different list. We hope that readers will find it useful, and that they will be able to interpret the information in convergent but original ways.

We also hope that our results will help to better understand the field and its current state and trends, and eventually allow researchers to situate their own understanding of the conceptual change phenomenon within the spectrum of available propositions, as these are more or less supported by the community. We also hope that this work will allow the community to better define what conceptual change is, and understand how it should be discussed in order to avoid misunderstanding about its ambitions.

At the end, we believe that our work, by its capacity to illustrate the strong diversity and great number of CC models through the exhaustive (and weighted) inventory available in Table 3, could thus encourage the advent of more comparative research that could strive to discriminate between different propositions and between their components, in order to better contribute to the 'scientificity' of the field.

Notes

1. Vygotsky, Bandura, Ausubel, Anderson, Popper, Lakatos, Laudan and Feyerabend could also be considered.
2. Objective initiatives have, however, been undertaken to present summaries of these two approaches (Özdemir & Clark, 2007).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Fonds Québécois de Recherche Société et Culture (FRQSC: Grant no. 2019-SE3-252952); the Social Sciences and Humanities Research Council of Canada (SSHRC: Grant no. 111723); the Faculté des Sciences de l'Éducation of the Université du Québec à Montréal (UQAM); and the Équipe de recherche en éducation scientifique et technologique (ÉREST).

Notes on contributors

Patrice Potvin (Ph. D.) is a professor in the field of early childhood at the Université du Québec à Montréal (UQAM) in Canada. Her research interest focus on the cognitive and cerebral mechanisms involved in early learning, particularly in science and reading. She is also interested more generally in the role of executive functions in early childhood development and learning and the identification of effective educational interventions.

Lucian Nenciovici (M. A.) is a Ph.D. student in science and technology education, pedagogical counsellor at the Commission scolaire de l'Énergie and lecturer at the Université du Québec à Trois-Rivières (UQTR) in Canada. Her research interests focus on technological design process with the goal of raising students' interest.

Guillaume Malenfant-Robichaud (M. A.) is a contributor of the S&T Education Research Team (EREST) and a mathematics and science adult educator. His research interests focus on conceptual change through a neuro-educational approach particularly in chemistry education.

François Thibault (M. A.) is a Ph. D. student in science and technology education and a lecturer at the Université du Québec à Montréal (UQAM). His research interests are mostly focused on conceptual change and its underlying cognitive processes.

Ousmane Sy (Ph. D.) is a professor of science and technology at the Université du Quebec à Trois-Rivières (UQTR) in Canada and co-director of the Interdisciplinary Laboratory in Pedagogical Integration of ICT (LIIPTIC). He is specialized in the study of the dynamics of interactions between the dimensions of effective teaching practice and students' interest in S&T.

Mohamed Amine Mahhou is an undergraduate student in S&T high school education at the Université du Québec à Montréal. Since he joined the S&T Education Research Team (STERT/EREST), his main interest has been context-based approaches to physics teaching with the goal of raising students' interest. He also works as a research assistant under the leadership of Patrick Charland in a project focusing on student engagement, and with Olivier Arvisais in projects focusing on education in the context of emergency.

Alex Bernard (M. A.) is a contributor of the S&T Education Research Team (EREST) and an elementary teacher working with children with special needs in reading, writing and mathematics. His research interests focus on developing effective practice for teaching French grammar and syntax at the elementary level.

Geneviève Allaire-Duquette (Ph. D.) is currently pursuing her postdoctoral research at Tel Aviv University's School of Education. Her work focuses on understanding mechanisms of reasoning in science and mathematics using cognitive neuroscience methods. More specifically, she is interested in the mechanisms underlying the ability to overcome intuitive interference to formal/logical reasoning.

Jérémie Blanchette Sarrasin (M. A.) is a Ph.D. student in the field of Mind, Brain and Education and a teacher at the Université du Québec à Montréal (UQAM) in Canada. Her research interests focus on the cerebral mechanisms involved in reasoning in science and mathematics using cognitive neuroscience methods.

Lorie-Marlène Brault Foisy is a professor of science and technology education at the Faculty of Education of the University of Quebec in Montreal (UQAM). A former teacher (7 years), he has also worked in the development of numerous training programmes. Holder of the Research Chair on interest of young people towards science and technology (CRIJEST) and director of the Science and technology education research team research team (EREST), his research and development interests focus on student interest in science, open science learning, computer-assisted learning, teacher training, and conceptual change through a neuro-educational approach (cognitive control, inhibition and engagement). Author of more than 360 publications and papers (in journals such as Studies in Science Education, Frontiers in Human Neuroscience, Research in Science Education, Journal of Research in Science Teaching, etc.), he recently published, in Presses de l'Université Laval, the book 'Making students learn school science and technology: Using Epistemology, didactics, cognitive sciences and neuroscience for teaching' (in French). In 2014, he was appointed a member of the Royal Society of Canada.

Nancy Brouillette (M. A.) is a Ph. D. student in science and technology education and a teacher at the Université du Québec à Montréal (UQAM) in Canada with research focus on neuroeducation and meta-analysis methodologies.

Audrey-Anne St-Aubin is a contributor of the S&T Education Research Team (EREST), a graduate student of science education at Université du Québec à Montréal (UQAM) and a junior environmental project manager.

Patrick Charland (Ph. D.) is a professor of science and technology education at the Université du Québec à Montréal (UQAM) in Canada and co-holder of the UNESCO Research Chair in Curriculum Development (CUDC). He is specialized in the study of the dynamic of interactions between the dimensions of engagement and situational interest in real time with the collection and analysis of behavioral, cognitive and emotional data.

Steve Masson (Ph. D.) is a professor of neuroeducation at the Université du Québec à Montréal (UQAM) in Canada and director of the Laboratory for Research in Neuroeducation (LRN). Using the functional magnetic resonance imaging, he studies the brain mechanisms related to school learning and teaching. His research interests focus on the effects of teaching practices on the brain, and the role of neuroscience in teaching.

Martin Riopel (Ph. D.) is a professor of science and technology education and vice-dean of research at the Université du Québec à Montréal (UQAM) in Canada. His research interests focus on computer-assisted learning, serious games, learning models and neuroeducation. He also holds the Research Chair on Educational Innovation (CRIP) at the Paris-Saclay University in France.

Chin-Chung Tsai (Ph. D.) is currently a Chair Professor and Dean for School of Learning Informatics, National Taiwan Normal University, Taipei, Taiwan. He is also the Director of the Institute for Research Excellence in Learning Sciences, National Taiwan Normal University. Since July 2009, he has been appointed as the Co-Editor of Computers & Education (SSCI, IF= 5.627, rank 3/243). He is also currently served as the Editor of International Journal of Science Education (indexed in SSCI). His research interests deal largely with constructivism, epistemic beliefs, and various types of technology-enhanced (such as VR, AR, game) instruction. He has a publication record of more than 300 SSCI papers in recent 20 years.

Michel Bélanger (Ph. D.) is a professor of science and technology education at the Université du Québec à Rimouski (UQAR) in Canada. His research interests focus on the history of science education and representational pluralism in science learning.

Pierre Chastenay (Ph. D.) is an astronomer and a professor of science and technology education at the Université du Québec à Montréal (UQAM) in Canada. He mainly does research in science teaching and astronomy teaching at the elementary level. His current projects deal with spatial abilities and astronomy education, teaching the phases of the Moon, Teaching astronomy by doing astronomy like astronomers, and using a full-dome digital planetarium to teach astronomical concepts.

ORCID

Patrice Potvin http://orcid.org/0000-0002-1623-2362
Lucian Nenciovici http://orcid.org/0000-0002-3004-7059
Guillaume Malenfant-Robichaud http://orcid.org/0000-0002-3515-3045
François Thibault http://orcid.org/0000-0002-8050-9362
Ousmane Sy http://orcid.org/0000-0002-9605-6636
Mohamed Amine Mahhou http://orcid.org/0000-0001-8328-654X
Alex Bernard http://orcid.org/0000-0001-7088-7039
Geneviève Allaire-Duquette http://orcid.org/0000-0002-7506-0310
Jérémie Blanchette Sarrasin http://orcid.org/0000-0003-0478-8125
Lorie-Marlène Brault Foisy http://orcid.org/0000-0003-1594-5915
Nancy Brouillette http://orcid.org/0000-0002-0852-6248
Audrey-Anne St-Aubin http://orcid.org/0000-0002-2235-5780
Patrick Charland http://orcid.org/0000-0001-5893-7443
Steve Masson http://orcid.org/0000-0002-7228-5098
Martin Riopel http://orcid.org/0000-0003-0187-6218
Chin-Chung Tsai http://orcid.org/0000-0001-7744-9971
Michel Bélanger http://orcid.org/0000-0002-1988-8455
Pierre Chastenay http://orcid.org/0000-0002-6825-0538

References

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education*, *88*(5), 785–810. https://doi.org/10.1002/sce.10143

Alexander, P. A. (1998). Positioning conceptual change within a model of domain literacy. In B. Guzetti & C. Hynd (Eds.), *Perspectives on conceptual change: Multiple ways to understanding, knowing and learning in a complex world* (pp. 55–76). Lawrence Erlbaum associates.

Ali, K. S. (1990). *Instructiestrategieën voor het activeren van preconcepties* [Instructional strategies for activating preconceptions]. Proefschrift Katholieke Universiteit Brabant.

Alsop, S., & Watts, M. (1997). Sources from a Somerset villagex. *Science Education*, *81*(6), 633–650. https://doi.org/10.1002/(SICI)1098-237X(199711)81:6<633::AID-SCE2>3.0.CO;2-J

Amin, T. G., Smith, C. L., & Wiser, M. (2014). Student Conceptions and Conceptual Change. Three overlapping phases of research. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (Vol. 2, pp. 57–81). Routledge.

Anders, P., & Commeyras, M. (1998). A feminist commentary on four science education vignettes. In B. Guzetti & C. Hynd (Eds.), *Perspectives on conceptual change: Multiple ways to understanding, knowing and learning in a complex world* (pp. 133–144). Lawrence Erlbaum associates.

Astolfi, J.-P., & Develay, M. (1998). *La didactique des sciences*. Presses universitaires de France.

Bachelard, G. (1967). *La formation de l'esprit scientifique*. Librairie Vrin.

Banet, E., & Núñez, F. (1997). Teaching and learning about human nutrition: A constructivist approach. *International Journal of Science Education*, *19*(10), 1169–1194. https://doi.org/10.1080/0950069970191005

Banks, E. C. (2004). The philosophical roots of Ernst Mach's economy of thought. *Synthese*, *139*(1), 23–53. https://doi.org/10.1023/B:SYNT.0000021306.66850.a3

Biemans, H. J. A., & Simons, P. R.-J. (1996). Contact-2: A computer-assisted instructional strategy for promoting conceptual change. *Instructional Science*, *24*(2), 157–176. https://doi.org/10.1007/bf00120487

Blank, L. M. (2000). A metacognitive learning cycle: A better warranty for student understanding? *Science Education*, *84*(4), 486–506. https://doi.org/10.1002/1098-237X(200007)84:4<486::AID-SCE4>3.0.CO;2-U

Bliss, J., & Ogborn, J. (1994). Force and motion from the beginning. *Learning and Instruction*, *4*(1), 7–25. https://doi.org/10.1016/0959-4752(94)90016-7

Brown, D. E. (1993). Refocusing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching*, *30*(10), 1273–1290. https://doi.org/10.1002/tea.3660301009

Brown, D. E. (2014). Students' conceptions as dynamically emergent structures. *Science & Education*, *23*(7), 1463–1483. https://doi.org/10.1007/s11191-013-9655-9

Caravita, S., & Hallden, O. (1994). Reframing the problem of conceptual change. *Learning and Instruction*, *4*(1), 89–111. https://doi.org/10.1016/0959-4752(94)90020-5

Carey, S. (1985). *Conceptual change in childhood*. MIT Press.

Carey, S. (2009). *The origin of concepts*. Oxford University Press.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction*, *15*(1), 1–40. https://doi.org/10.1207/s1532690xci1501_1

Chi, M. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere & H. Feigl (Eds.), *Cognitive models of science: Minnesota studies in the philosophy of science* (pp. 129–186). University of Minnesota Press.

Chi, M. T. H., Slotta, J. D., & De Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction*, *4*(1), 27–43. https://doi.org/10.1016/0959-4752(94)90017-5

Chinn, C. A., & Samarapungavan, A. (2008). Learning to use scientific models: Multiple dimensions of conceptual change. In R. A. Duschl & R. E. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 191–225). Sense Publishers.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition. *Review of Educational Research*, *63*(1), 1–49. https://doi.org/10.3102/00346543063001001

Chiu, M.-H., Lin, J.-W., & Chou, C. C. (2016). Content analysis of conceptual change research and practice in science education: From localization to globalization. In M.-H. Chiu (Ed.), *Science education research and practices in Taiwan*. Springer. pp. 89-131.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching*, *30*(10), 1241–1257. https://doi.org/10.1002/tea.3660301007

Cobern, W. W. (1996). Worldview theory and conceptual change in science education. *Science Education*, *80*(5), 579–610. https://doi.org/10.1002/(SICI)1098-237X(199609)80:5<579::AID-SCE5>3.0.CO;2-8

Dawson, C. (2014). Towards a conceptual profile: Rethinking conceptual mediation in the light of recent cognitive and neuroscientific findings. *Research in Science Education*, *44*(3), 389–414. https://doi.org/10.1007/s11165-013-9388-4

Dekkers, P. J. J. M., & Thijs, G. D. (1998). Making productive use of students' initial conceptions in developing the concept of force. *Science Education*, *82*(1), 31–51. https://doi.org/10.1002/(SICI)1098-237X(199801)82:1<31::AID-SCE3>3.0.CO;2-1

Demastes, S. S., Good, R. G., & Peebles, P. (1996). Patterns of conceptual change in evolution. *Journal of Research in Science Teaching*, *33*(4), 407–431. https://doi.org/10.1002/(SICI)1098-2736(199604)33:4<407::AID-TEA4>3.0.CO;2-W diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, *10*(2), 105–225. https://doi.org/10.1080/07370008.1985.9649008

diSessa, A. A. (2006). A history of conceptual change research: Threads and fault lines. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 265–281). Cambridge University press.

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive conception of knowledge. *Educational Psychologist*, *33*(2–3), 109–128. https://doi.org/10.1080/00461520.1998.9653294

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61–84. https://doi.org/10.1080/03057267808559857

Driver, R., Leach, J., & Millar, R. (1996). *Young peoples' images of science*. McGraw-Hill Education.

Duit, R. (1999). Conceptual change approaches in science education. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change*. Pergamon. pp. 103-129.

Duit, R., Goldberg, F., & Niedderer, H. (1992). *Research in physics learning: Theoretical issues and empirical studies*. Institute for Science Education at the University of Kiel.

Duit, R., & Treagust, D. (2003). Conceptual change - A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*(6), 671–688. https://doi.org/10.1080/09500690305016

Duschl, R. A., & Gitomer, D. H. (1991). Epistemological perspectives on conceptual change: Implications for educational practice. *Journal of Research in Science Teaching*, *28*(9), 839–858. https://doi.org/10.1002/tea.3660280909

Dykstra, D. I., Boyle, F. C., & Monarch, I. (1992). Studying conceptual change in learning physics. *Science Education*, *76*(6), 615–652. https://doi.org/10.1002/sce.3730760605

Ebenezer, J. V., & Connor, S. (1998). *Learning to teach science: A model for the twenty-first century*. Prentice-Hall, Inc.

Evans, S. B. T. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences*, *7*(10), 454–459. https://doi.org/10.1016/j.tics.2003.08.012

Festinger, L. (1957). *A theory of cognitive dissonance*. Stanford University Press.

Furberg, A., & Arnseth, H. C. (2009). Reconsidering conceptual change from a socio-cultural perspective: Analyzing students' meaning making in genetics in collaborative learning activities. *Cultural Studies of Science Education*, *4*(1), 157–191. https://doi.org/10.1007/s11422-008-9161-6

Galbraith, D. (1992). Conditions for discovery through writing. *Instructional Science*, *21*(1), 45–71. https://doi.org/10.1007/bf00119655

Galili, I., & Hazan, A. (2000). Learners' knowledge in optics: Interpretation, structure and analysis. *International Journal of Science Education*, *22*(1), 57–88. https://doi.org/10.1080/095006900290000

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*(2), 155–170. https://doi.org/10.1016/S0364-0213(83)80009-3

Gilbert, J. K., Osborne, R. J., & Fensham, P. J. (1982). Children's science and its consequences for teaching. *Science Education*, *66*(4), 623–633. https://doi.org/10.1002/sce.3730660412

Giordan, A., & DeVecchi, G. (1987). *Les origines du savoir*. Delachaux.

Givry, D., & Roth, W.-M. (2006). Toward a new conception of conceptions: Interplay of talk, gestures, and structures in the setting. *Journal of Research in Science Teaching*, *43*(10), 1086–1109. https://doi.org/10.1002/tea.20139

Glaser, R. (1990). The re-emergence of learning theory within instructional research. *American Psychologist*, *45*(1), 29–39. https://doi.org/10.1037/0003-066X.45.1.29

Glasson, G. E., & Lalik, R. V. (1993). Reinterpreting the learning cycle from a social constructivist perspective: A qualitative study of teachers' beliefs and practices. *Journal of Research in Science Teaching*, *30*(2), 187–207. https://doi.org/10.1002/tea.3660300206

Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal processes during conceptual change. *Educational Psychology Review*, *15*(2), 147–179. https://doi.org/10.1023/a:1023477131081

Guzetti, B., & Hynd, C. (1998). *Perspectives on conceptual change: Multiple ways to understanding, knowing and learning in a complex world*. Lawrence Erlbaum associates.

Guzzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly*, *28*(2), 117–159. https://doi.org/10.2307/747886

Halldén, O. (1999). Conceptual change and contextualization. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 53–65). Elsevier Science.

Havu-Nuutinen, S. (2005). Examining young children's conceptual change process in floating and sinking from a social constructivist perspective. *International Journal of Science Education*, *27*(3), 259–279. https://doi.org/10.1080/0950069042000243736

Hewson, M. (1981, 7-11 April). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning (Parts I and 2). *Paper presented at the National Association for Research in Science Teaching (NARST)*, Ellenville, NY.

Hewson, P. W. (1980, 7-11 April). A case study of the effect of metaphysical commitments on the learning of a complex scientific theory. *Paper presented at the Annual meeting of the American Educational Research Association (AERA)*, Boston (MA), USA.

Hsu, Y.-S. (2008). Learning about seasons in a technologically enhanced environment: The impact of teacher-guided and student-centered instructional approaches on the process of students' conceptual change. *Science Education*, *92*(2), 320–344. https://doi.org/10.1002/sce.20242

Isabelle, A. D., & De Groot, C. (2008). Alternate conceptions of preservice elementary teachers: The Itakura method. *Journal of Science Teacher Education*, *19*(5), 417–435. https://doi.org/10.1007/s10972-008-9105-8

Itakura, K., Kamisako, A., & Shoji, K. (1964). Instruction and learning of the concept of force in statics based on Kasetsu-Jikken-Jugyo (Hypothesis-experiment-instruction): A new method of science teaching. *The Journal of Science Education* [In Japanese], *6*(11), 42–57.

Kang, S., Scharmann, L. C., Noh, T., & Koh, H. (2005). The influence of students' cognitive and motivational variables in respect of cognitive conflict and conceptual change. *International Journal of Science Education*, *27*(9), 1037–1058. https://doi.org/10.1080/09500690500038553

Karplus, R., & Thier, H. D. (1967). A new look at elementary school science. In *Science curriculum improvement study*. 105. Rand McNally and company, Chicago.

Kattmann, U. (2008). Learning biology by means of anthropomorphic conceptions? In M. Hamman, M. Reiss, C. Boulter, & S. D. Tunniciffe (Eds.), *Biology in context: Learning and teaching for the 21st century*. Institute of Education, University of London. 345.

Kelly, G. J., & Green, J. (1998). The social nature of knowing: Toward a sociocultural perspective on conceptual change. In B. Guzetti & C. Hynd (Eds.), *Perspectives on conceptual change: Multiple ways to understanding, knowing and learning in a complex world* (pp. 145–182). Lawrence Erlbaum associates.

Klein, P. D. (2004). Constructing scientific explanations through writing. *Instructional Science*, *32*(3), 191–231. https://doi.org/10.1023/B:TRUC.0000024189.74263.bd

Klopfer, L. E., Champagne, A. B., & Gunstone, R. F. (1983). Naive knowledge and science learning. *Research in Science & Technological Education*, *1*(2), 173–183. https://doi.org/10.1080/0263514830010205

Koponen, I. T. (2014). Introduction: Conceptual change and its models. *Science & Education*, *23*(7), 1411–1412. https://doi.org/10.1007/s11191-014-9689-7

Kuhn, T. S. (1962). *La structure des révolutions scientifiques*. Champs-Flammarion.

Lawson, A., Abraham, M. R., & Renner, J. W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills NARST Monograph No. 1*. National Association for Research in Science Teaching.

Li, S. C., Law, N., & Lui, K. F. A. (2006). Cognitive perturbation through dynamic modelling: A pedagogical approach to conceptual change in science. *Journal of Computer Assisted Learning*, *22*(6), 405–422. https://doi.org/10.1111/j.1365-2729.2006.00187.x

Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction*, *11*(4–5), 357–380. https://doi.org/10.1016/S0959–4752(00)00037-2

Lin, J.-W., Yen, M.-H., Liang, J.-C., Chiu, M.-H., & Guo, C.-J. (2016). Examining the factors that influence students' science learning processes and their learning outcomes: 30 years of conceptual change research. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(9), 2617–2646. https://doi.org/10.12973/eurasia.2016.000600a

Lin, T.-C., Lin, T.-J., & Tsai, -C.-C. (2014). Research trends in science education from 2008 to 2012: A systematic content analysis of publications in selected journals. *International Journal of Science Education*, *36*(8), 1346–1372. https://doi.org/10.1080/09500693.2013.864428

Lin, T. J., Lin, T. C., Potvin, P., & Tsai, C. C. (2019). Research trends in science education from 2013 to 2017: a systematic content analysis of publications in selected journals. *International Journal of Science Education*, 41(3), 367–387.

Linn, M. C. (2008). Teaching for conceptual change: Distinguishing or extinguishing ideas. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 694–722). Routledge.

Locke, J. (1824). The works of John Locke: in nine volumes (Vol. 7). C. and J. Rivington.

Lombardi, D., Nussbaum, E. M., & Sinatra, G. M. (2016). Plausibility judgments in conceptual change and epistemic cognition. *Educational Psychologist*, *51*(1), 35–56. https://doi.org/10.1080/00461520.2015.1113134

Mach, E. (1908). *La connaissance et l'erreur*. Flammarion.

Mason, L. (2001). Introduction to special issue on conceptual change. *Learning and Instruction*, *11*(4), 259–263. https://doi.org/10.1016/S0959-4752(00)00032–3

Matthews, M. R. (2002). Constructivism and science education: A further appraisal. *Journal of Science Education and Technology*, *11*(2), 121–134. https://doi.org/10.1023/A:101466131

Minstrell, J. (1989). Teaching science for understanding. In L. B. Resnick & L. E. Klopfer (Eds.), *Toward the thinking curriculum* (pp. 129–149). Association for Supervision and Curriculum Development.

Miyake, N. (2008). Conceptual change through collaboration. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 453–478). Routledge.

Mortimer, E. F. (1995). Conceptual or conceptual profile change? *Science and Education*, *3*(3), 267–285. https://doi.org/10.1007/BF00486624

Myers, J., & Alvermann, D. (1998). A critical postmodernist perspective on the vignettes of conceptual change. In B. Guzetti & C. Hynd (Eds.), *Perspectives on conceptual change: Multiple ways to understanding, knowing and learning in a complex world* (pp. 183–195). Lawrence Erlbaum associates.

Nadelson, L. S., Heddy, B. C., Jones, S., Taasoobshirazi, G., & Johnson, M. (2018). Conceptual change in science teaching and learning: Introducing the dynamic model of conceptual change. *International Journal of Educational Psychology*, *7*(2), 151–195. https://doi.org/10.17583/ijep.2018.3349

Neale, D. C., Smith, D., & Johnson, V. G. (1990). Implementing conceptual change teaching in primary science. *The Elementary School Journal*, *91*(2), 109–131. https://doi.org/10.1086/461641

Niedderer, H., & Schecker, H. (1992). Towards an explicit description of cognitive systems for research in physics learning. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 74–98). Institute for Sc. Education at the Univ. of Kiel.

Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual change in limited or inappropriate propositional hierarchies leading to empowerment of learners. *Science Education*, *86*(4), 548–571. https://doi.org/10.1002/sce.10032

Nussbaum, J., & Novick, S. (1981, April). Creating cognitive dissonance between students' preconceptions to encourage individual cognitive accommodation and a group cooperative construction of a scientific model. *Paper presented at the American Educational Research Association (AERA)*, Los Angeles.

Nussbaum, J., & Novick, S. (1982). Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. *Instructional Science*, *11*(3), 183–200. https://doi.org/10.1007/BF00414279

Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist*, *44*(1), 20–40. https://doi.org/10.1080/00461520802616267

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education*, *67*(4), 489–508. https://doi.org/10.1002/sce.3730670406

Özdemir, G., & Clark, D. B. (2007). An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(4), 351–361. https://doi.org/10.12973/ejmste/75414

Palmer, D. (2005). A motivational view of constructivist-informed teaching. *International Journal of Science Education*, *27*(15), 1853–1881. https://doi.org/10.1080/09500690500339654

Pauen, S. (1999). The development of ontological categories. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 15–31). Elsevier Science.

Piaget, J. I. B. (1968). *La psychologie de l'enfant*. Presses Universitaires de France.

Pines, A. L., & West, L. H. T. (1986). Conceptual understanding and science learning: An interpretation of research within a sources-of-knowledge framework. *Science Education*, *70*(5), 583–604. https://doi.org/10.1002/sce.3730700510

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*(2), 167–199. https://doi.org/10.3102/00346543063002167

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Potvin, P. (2013). Proposition for improving the classical models of conceptual change based on neuroeducational evidence: Conceptual prevalence. *Neuroeducation*, *1*(2), 16–43. https://doi.org/10.24046/neuroed.20130201.16

Prawat, R. S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research synthesis. *Review of Educational Research*, *59*(1), 1–41. https://doi.org/10.3102/00346543059001001

Roschelle, J. (1991). MicroAnalysis of qualitative physics. *Paper at Annual meeting of the AERA*, Chicago, IL.

Roth, K. J. (1985). Conceptual change learning and students processing of science texts. *Paper presented at the Annual meeting of the American Educational Research Association*, Chicago, IL.

Rousseau, J. J. (1892). Rousseau's Émile: or, Treatise on education (Vol. 20). D. Appleton. Chicago

Schwedes, H., & Schmidt, D. (1992). Conceptual change: A case study and theoretical comments. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 188–202). Institute for Science Education at the University of Kiel.

Schwitzgebel, E. (1999). Children's theories and the drive to explain. *Science & Education*, *8*(5), 457–488. https://doi.org/10.1023/a:1008633709447

She, H.-C. (2004). Fostering radical conceptual change through dual-situated learning model. *Journal of Research in Science Teaching*, *41*(2), 142–164. https://doi.org/10.1002/tea.10130

Sinatra, G. M., & Pintrich, P. R. (2003). *Intentional conceptual change*. Lawrence Erlbaum Associates.

Solomon, J. (1983). Learning about energy: How pupils think in two domains. *European Journal of Science Education*, *5*(1), 49–59. https://doi.org/10.1080/0140528830050105

Spiro, R. J., Feltovich, P. J., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 498–531). Cambridge University Press.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147–176). Sunny Press.

Talanquer, V. (2006). Commonsense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education*, *83*(5), 811. https://doi.org/10.1021/ed083p811

Tao, P.-K., & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, *36*(7), 859–882. https://doi.org/10.1002/(SICI)1098-2736(199909)36:7<859::AID-TEA7>3.0.CO;2-J

Taylor, A. K., & Kowalski, P. (2004). Naïve psychological science: The prevalence, strength, and sources of misconceptions. *The Psychological Record*, *54*(1), 15–25. https://doi.org/10.1007/bf03395459

Thagard, P. (1992). *Conceptual revolutions*. Princeton University Press.

Thorley, N. R., & Stofflett, R. T. (1996). Representation of the conceptual change model in science teacher education. *Science Education*, *80*(3), 317–339. https://doi.org/10.1002/(SICI)1098-237X(199606)80:3<317::AID-SCE3>3.0.CO;2-H

Tiberghien, A. (1994). Modeling as a basis for analyzing teaching-learning situations. *Learning and Instruction*, *4*(1), 71–87. https://doi.org/10.1016/0959-4752(94)90019-1

Tirosh, D., & Stavy, R. (1999). Intuitive rules: A way to explain and predict students' reasoning. In D. Tirosh (Ed.), *Forms of mathematical knowledge: Learning and teaching with understanding* (pp. 51–66). Springer Netherlands.

Toulmin, S. (1972). *Human understanding, Volume 1: The collective use and development of concepts*. Clarendon Press.

Tsai, -C.-C. (2000). Enhancing science instruction: The use of 'conflict maps.'. *International Journal of Science Education*, *22*(3), 285–302. https://doi.org/10.1080/095006900289886

Tsukamoto, K. (2017, 21-25 August). Mechanics programmes under the Japanese instruction theory "kasetsu". *Paper presented at the European Science Education Research Association (ESERA)*, Dublin, Ireland.

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. *Science Education*, *81*(4), 387–404. https://doi.org/10.1002/(SICI)1098-237X(199707)81:4<387::AID-SCE2>3.0.CO;2-8

Tytler, R., & Prain, V. (2010). A framework for rethinking learning in science from recent cognitive science perspectives. *International Journal of Science Education*, *32*(15), 2055–2078. https://doi.org/10.1080/09500690903334849

Viennot, L. (1979). *Le raisonnement spontané en dynamique élémentaire*. Hermann.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction*, *4*(1), 45–69. https://doi.org/10.1016/0959-4752(94)90018-3

Vosniadou, S. (2008a). Conceptual change research: An introduction. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. xiii–xxviii). Routledge.

Vosniadou, S. (2008b). *International handbook of research on conceptual change*. Routledge.

Vosniadou, S., & Skopeliti, I. (2014). Conceptual change from the framework theory side of the fence. *Science & Education*, *23*(7), 1427–1445. https://doi.org/10.1007/s11191-013-9640-3

Wang, T., & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology*, *16*(2), 103–116. https://doi.org/10.1016/0361-476X(91)90031-F

White, B. Y. (1993). ThinkerTools: Causal Models, Conceptual Change, And Science Education. *Cognition and Instruction*, *10*(1), 1–100. https://doi.org/10.1207/s1532690xci1001_1

White, R. T. (1994). Conceptual and conceptional change. *Learning and Instruction*, *4*(1), 117–121. https://doi.org/10.1016/0959-4752(94)90022-1

Appendix 1. The complete corpus (n = 245)

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as Conceptual Change: Factors Mediating the Development of Preservice Elementary Teachers' Views of Nature of Science. Science Education, 88(5), 785–810. doi:10.1002/sce.10143

Abd-El-Khalick, F., & Akerson, V. L. (2007). On the Role and Use of 'Theory' in Science Education Research: A Response to Johnston, Southerland, and Sowell. Science Education, 91(1), 187–194. doi:10.1002/sce.20189

Adadan, E., Trundle, K. C., & Irving, K. E. (2010). Exploring grade 11 students' conceptual pathways of the particulate nature of matter in the context of multirepresentational instruction. Journal of Research in Science Teaching, 47(8), 1004–1035. doi:10.1002/tea.20366

Allen, M. (2010). Learner error, affectual stimulation, and conceptual change. Journal of Research in Science Teaching, 47(2), 151–173. doi:10.1002/tea.20302

Allen, M. (2015). Preschool children's taxonomic knowledge of animal species. Journal of Research in Science Teaching, 52(1), 107–134. doi:10.1002/tea.21191

Alsop, S., & Watts, M. (1997). Sources from a Somerset village: A model for informal learning about radiation and radioactivity. Science Education, 81(6), 633–650. doi:10.1002/(SICI)1098-237X(199,711)81:6 < 633::AID-SCE2 > 3.0.CO;2-J

Amin, T. G. (2015). Conceptual Metaphor and the Study of Conceptual Change: Research Synthesis and Future Directions. International Journal of Science Education, 37(5–6), 966–991. doi:10.1080/09500693.2015.1025313

Anderson, O. R. (1992). Some interrelationships between constructivist models of learning and current neurobiological theory, with implications for science education. Journal of Research in Science Teaching, 29(10), 1037–1058. doi:10.1002/tea.3660291004

Arnold, M., & Millar, R. (1996). Learning the Scientific 'Story': A Case Study in the Teaching and Learning of Elementary Thermodynamics. Science Education, 80(3), 249–281. doi:10.1002/(SICI)1098-237X(199,606)80:3 < 249::AID-SCE1 > 3.0.CO;2-E

Baldy, E. (2007). A New Educational Perspective for Teaching Gravity. International Journal of Science Education, 29(14), 1767–1788. doi:10.1080/09500690601083367

Barnett, M., & Morran, J. (2002). Addressing Children's Alternative Frameworks of the Moon's Phases and Eclipses. International Journal of Science Education, 24(8), 859–879. doi:10.1080/09500690110095276

Basili, P. A., & Sanford, J. P. (1991). Conceptual Change Strategies and Cooperative Group Work in Chemistry. Journal of Research in Science Teaching, 28(4), 293–304. doi:10.1002/tea.3660280403

Becker, N. M., & Cooper, M. M. (2014). College chemistry students' understanding of potential energy in the context of atomic–molecular interactions. Journal of Research in Science Teaching, 51(6), 789–808. doi:10.1002/tea.21159

Beeth, M. E. (1998a). Teaching for conceptual change: Using status as a metacognitive tool. Science Education, 82(3), 343–356. doi:10.1002/(SICI)1098-237X(199,806)82:3 < 343::AID-SCE3 > 3.0.CO;2-C

Beeth, M. E. (1998b). Teaching science in fifth grade: Instructional goals that support conceptual change. Journal of Research in Science Teaching, 35(10), 1091–1101. doi:10.1002/(SICI)1098–2736(199,812)35:10 < 1091::AID-TEA3 > 3.0.CO;2-S

Beeth, M. E., & Hewson, P. W. (1999). Learning goals in an exemplary science teacher's practice: Cognitive and social factors in teaching for conceptual change. Science Education, 83(6), 738–760. doi:10.1002/(SICI)1098-237X(199911)83:6 < 738::AID-SCE6 > 3.0.CO;2–9

Bell, R. L., Mulvey, B. K., & Maeng, J. L. (2016). Outcomes of Nature of Science Instruction along a Context Continuum: Preservice Secondary Science Teachers' Conceptions and Instructional Intentions. International Journal of Science Education, 38(3), 493–520. doi:10.1080/09500693.2016.1151960

Bell, R. L., & Trundle, K. C. (2008). The use of a computer simulation to promote scientific conceptions of moon phases. Journal of Research in Science Teaching, 45(3), 346–372. doi:10.1002/tea.20227

Bendall, S., Goldberg, F., & Galili, I. (1993). Prospective elementary teachers' prior knowledge about light. Journal of Research in Science Teaching, 30(9), 1169–1187. doi:10.1002/tea.3660300912

Biemans, H. J. A., Deel, O. R., & Simons, P. R.-J. (2001). Differences between successful and less successful students while working with the CONTACT-2 strategy. Learning and Instruction, 11(4–5), 265–282. doi:10.1016/S0959-4752(00)00033–5

Bliss, J., & Ogborn, J. (1994). Force and motion from the beginning. Learning and Instruction, 4(1), 7–25. doi:10.1016/0959-4752(94)90016–7

Blown, E. J., & Bryce, T. G. K. (2006). Knowledge Restructuring in the Development of Children's Cosmologies. International Journal of Science Education, 28(12), 1411–1462. doi:10.1080/09500690600718062

Broughton, S. H., Sinatra, G. M., & Nussbaum, E. M. (2013). 'Pluto Has Been a Planet My Whole Life!' Emotions, Attitudes, and Conceptual Change in Elementary Students' Learning about Pluto's Reclassification. Research in Science Education, 43(2), 529–550. doi:10.1007/s11165-011-9274-x

Brown, D. E. (1992). Using Examples and Analogies to Remediate Misconceptions in Physics: Factors Influencing Conceptual Change. Journal of Research in Science Teaching, 29(1), 17–34. doi:10.1002/tea.3660290104

Brown, D. E. (1993). Refocusing core intuitions: A concretising role for analogy in conceptual change. Journal of Research in Science Teaching, 30(10), 1273–1290. doi:10.1002/tea.3660301009

Bryce, T., & MacMillan, K. (2005). Encouraging Conceptual Change: The Use of Bridging Analogies in the Teaching of Action-Reaction Forces and the 'At Rest' Condition in Physics. Research Report. International Journal of Science Education, 27(6), 737–763. doi:10.1080/09500690500038132

Campanario, J. M. (2002). The Parallelism between Scientists' and Students' Resistance to New Scientific Ideas. International Journal of Science Education, 24(10), 1095–1110. doi:10.1080/09500690210126702

Caravita, S. (2001). A re-framed conceptual change theory? Learning and Instruction, 11(4–5), 421–429. doi:10.1016/S0959-4752(00)00039–6

Caravita, S., & Halldén, O. (1994). Re-framing the problem of conceptual change. Learning and Instruction, 4(1), 89–111. doi:10.1016/0959-4752(94)90020–5

Carvalho, G., Silva, R., Lima, N., Coquet, E., & Clement, P. (2004). Portuguese Primary School Children's Conceptions about Digestion: Identification of Learning Obstacles. Research Report. International Journal of Science Education, 26(9), 1111–1130. doi:10.1080/0950069042000177235

Case, J. M., & Fraser, D. M. (1999). An Investigation into Chemical Engineering Students' Understanding of the Mole and the Use of Concrete Activities To Promote Conceptual Change. International Journal of Science Education, 21(12), 1237–1249. doi:10.1080/095006999290048

Chambers, S. K., & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. Journal of Research in Science Teaching, 34(2), 107–123. doi:10.1002/(SICI)1098–2736(199,702)34:2 < 107::AID-TEA2 > 3.0.CO;2-X

Chang, C.-Y., & Barufaldi, J. P. (1999). The Use of a Problem-Solving-Based Instructional Model in Initiating Change in Students' Achievement and Alternative Frameworks. International Journal of Science Education, 21(4), 373–388. doi:10.1080/095006999290606

Cheng, P. C. H., & Shipstone, D. M. (2003a). Supporting Learning and Promoting Conceptual Change with Box and AVOW Diagrams. Part 1: Representational Design and Instructional Approaches. International Journal of Science Education, 25(2), 193–204. doi:10.1080/09500690210163206

Cheng, P. C. H., & Shipstone, D. M. (2003b). Supporting learning and promoting conceptual change with box and AVOW diagrams. Part 2: Their impact on student learning at A-level. International Journal of Science Education, 25(3), 291–305. doi:10.1080/09500690210163215

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. Learning and Instruction, 4(1), 27–43. doi:10.1016/0959-4752(94)90017–5

Chiang, W.-W., & Liu, C.-J. (2014). Scale of Academic Emotion in Science Education: Development and Validation. International Journal of Science Education, 36(6), 908–928. doi:10.1080/09500693.2013.830233

Chin, C., & Teou, L.-Y. (2009). Using Concept Cartoons in Formative Assessment: Scaffolding Students' Argumentation. International Journal of Science Education, 31(10), 1307–1332. doi:10.1080/09500690801953179

Chiu, M.-H., Chou, C.-C., & Liu, C.-J. (2002). Dynamic processes of conceptual change: Analysis of constructing mental models of chemical equilibrium. Journal of Research in Science Teaching, 39(8), 688–712. doi:10.1002/tea.10041

Chiu, M.-H., & Lin, J.-W. (2005). Promoting Fourth Graders' Conceptual Change of Their Understanding of Electric Current via Multiple Analogies. Journal of Research in Science Teaching, 42(4), 429–464. doi:10.1002/tea.20062

Clark, D., & Jorde, D. (2004). Helping Students Revise Disruptive Experientially Supported Ideas about Thermodynamics: Computer Visualisations and Tactile Models. Journal of Research in Science Teaching, 41(1), 1–23. doi:10.1002/tea.10097

Clark, D. B., Menekse, M., Ozdemir, G., D'Angelo, C. M., & Schleigh, S. P. (2014). Exploring sources of variation in studies of knowledge structure coherence: Comparing force meanings and force meaning consistency across two Turkish cities. Science Education, 98(1), 143–181. doi:10.1002/sce.21094

Cobern, W. W. (1996). Worldview theory and conceptual change in science education. Science Education, 80(5), 579–610. doi:10.1002/(SICI)1098-237X(199609)80:5 < 579::AID-SCE5 > 3.0.CO;2–8

Cross, R. T., & Pitekethly, A. (1988). Speed, Education and Children as Pedestrians: a Cognitive Change Approach to a Potentially Dangerous Naive Concept. International Journal of Science Education, 10(5), 531–540. doi:10.1080/0950069880100506

Dagher, Z. R. (1994). Does the use of analogies contribute to conceptual change? Science Education, 78(6), 601–614. doi:10.1002/sce.3730780605

Dawson, C. (2014). Towards a Conceptual Profile: Rethinking Conceptual Mediation in the Light of Recent Cognitive and Neuroscientific Findings. Research in Science Education, 44(3), 389–414. doi:10.1007/s11165-013-9388-4

Dawson, C. J., & Rowell, J. A. (1995). Snapshots of Uncertainty: A New Tool for the Identification of Students' Conceptions of Scientific Phenomena. Research in Science Education, 25(1), 89–100. doi:10.1007/BF02356462

Dega, B. G., Kriek, J., & Mogese, T. F. (2013). Students' conceptual change in electricity and magnetism using simulations: A comparison of cognitive perturbation and cognitive conflict. Journal of Research in Science Teaching, 50(6), 677–698. doi:10.1002/tea.21096

Demastes, S. S., Good, R. G., & Peebles, P. (1995). Students' conceptual ecologies and the process of conceptual change in evolution. Science Education, 79(6), 637–666. doi:10.1002/sce.3730790605

Demastes, S. S., Good, R. G., & Peebles, P. (1996). Patterns of conceptual change in evolution. Journal of Research in Science Teaching, 33(4), 407–431. doi:10.1002/(SICI)1098–2736(199604)33:4 < 407::AID-TEA4 > 3.0.CO;2-W

Demastes, S. S., Settlage, J., & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. Journal of Research in Science Teaching, 32(5), 535–550. doi:10.1002/tea.3660320509

Diakidoy, I.-A. N., & Kendeou, P. (2001). Facilitating conceptual change in astronomy: A comparison of the effectiveness of two instructional approaches. Learning and Instruction, 11(1), 1–20. doi:10.1016/S0959-4752(00)00011–6

diSessa, A. A., & Sherin, B. L. (1998). What Changes in Conceptual Change? International Journal of Science Education, 20(10), 1155–1191. doi:10.1080/0950069980201002

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the 'cognitive conflict' strategy for conceptual change: Some implications, difficulties, and problems. Science Education, 74(5), 555–569. doi:10.1002/sce.3730740506

Duit, R., Roth, W.-M., Komorek, M., & Wilbers, J. (1998). Conceptual Change cum Discourse Analysis to Understand Cognition in a Unit on Chaotic Systems: Towards an Integrative Perspective on Learning in Science. International Journal of Science Education, 20(9), 1059–1073. doi:10.1080/0950069980200904

Duit, R., Roth, W.-M., Komorek, M., & Wilbers, J. (2001). Fostering conceptual change by analogies – between Scylla and Charybdis. Learning and Instruction, 11(4–5), 283–303. doi:10.1016/S0959-4752(00)00034–7

Duit, R., & Treagust, D. F. (2003). Conceptual Change: A Powerful Framework for Improving Science Teaching and Learning. International Journal of Science Education, 25(6), 671–688. doi:10.1080/09500690305016

Duschl, R. A., & Gitomer, D. H. (1991). Epistemological perspectives on conceptual change: Implications for educational practice. Journal of Research in Science Teaching, 28(9), 839–858. doi:10.1002/tea.3660280909

Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. Science Education, 76(6), 615–652. doi:10.1002/sce.3730760605

Ebenezer, J., Chacko, S., Kaya, O. N., Koya, S. K., & Ebenezer, D. L. (2010). The effects of Common Knowledge Construction Model sequence of lessons on science achievement and relational conceptual change. Journal of Research in Science Teaching, 47(1), 25–46. doi:10.1002/tea.20295

Ebenezer, J. V., & Gaskell, P. J. (1995). Relational conceptual change in solution chemistry. Science Education, 79(1), 1–17. doi:10.1002/sce.3730790102

Elshout-Mohr, M., Van Hout-Wolters, B., & Broekkamp, H. (1999). Mapping situations in classroom and research: Eight types of instructional-learning episodes. Learning and Instruction, 9(1), 57–75. doi:10.1016/S0959-4752(98)00020–6

Enderle, P. J., Smith, M. U., & Southerland, S. (2009). Does Prior Knowledge Matter? Do Lamarckian Misconceptions Exist? A Critique of Geraedts and Boersma (2006). International Journal of Science Education, 31(18), 2527–2532. doi:10.1080/09500690802428106

Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. Journal of Research in Science Teaching, 39(10), 1001–1015. doi:10.1002/tea.10054

Eshach, H., Lin, T. C., & Tsai, C. C. (2017). Misconception of sound and conceptual change: A cross sectional study on students' materialistic thinking of sound. Journal of Research in Science Teaching, 55(5), 664–684. doi:10.1002/tea.21435

Eskin, H., & Ogan-Bekiroglu, F. (2013). Argumentation as a Strategy for Conceptual Learning of Dynamics. Research in Science Education, 43(5), 1939–1956. doi:10.1007/s11165-012-9339-5

Fellows, N. J. (1994). A window into thinking: Using student writing to understand conceptual change in science learning. Journal of Research in Science Teaching, 31(9), 985–1001. doi:10.1002/tea.3660310911

Felzmann, D. (2014). Using Metaphorical Models for Describing Glaciers. International Journal of Science Education, 36(16), 2795–2824. doi:10.1080/09500693.2014.936328

Fetherstonhaugh, T., & Treagust, D. F. (1992). Students' understanding of light and its properties: Teaching to engender conceptual change. Science Education, 76(6), 653–672. doi:10.1002/sce.3730760606

Finley, F., Lawrenz, F., & Heller, P. (1992). A summary of research in science education – 1990. Science Education, 76(3), 239–338. doi:10.1002/sce.3730760303

Fischer, H. E. (1993). Framework for conducting empirical observations of learning processes. Science Education, 77(2), 131–151. doi:10.1002/sce.3730770204

Fleer, M. (1992). Identifying teacher-child interaction which scaffolds scientific thinking in young children. Science Education, 76(4), 373–397. doi:10.1002/sce.3730760404

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. Learning and Instruction, 22(1), 62–77. doi:10.1016/j.learninstruc.2011.06.003

Gadgil, S., Nokes-Malach, T. J., & Chi, M. T. H. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. Learning and Instruction, 22(1), 47–61. doi:10.1016/j.learninstruc.2011.06.002

Geraedts, C. L., & Boersma, K. T. (2006). Reinventing Natural Selection. International Journal of Science Education, 28(8), 843–870. doi:10.1080/09500690500404722

Gil-Perez, D., & Carrascosa, J. (1990). What to do about science 'misconceptions.'. Science Education, 74(5), 531–540. doi:10.1002/sce.3730740504

Givry, D., & Roth, W.-M. (2006). Towards a New Conception of Conceptions: Interplay of Talk, Gestures, and Structures in the Setting. Journal of Research in Science Teaching, 43(10), 1086–1109. doi:10.1002/tea.20139

Givry, D., & Tiberghien, A. (2012). Studying Students' Learning Processes Used during Physics Teaching Sequence about Gas with Networks of Ideas and Their Domain of Applicability. International Journal of Science Education, 34(2), 223–249. doi:10.1080/09500693.2011.566289

Grimellini-Tomasini, N., Pecori-Balandi, B., Pacca, J. L., & Villani, A. (1993). Understanding conservation laws in mechanics: Students' conceptual change in learning about collisions. Science Education, 77(2), 169–189. doi:10.1002/sce.3730770206

Gunstone, R. F., Gray, C. R., & Searle, P. (1992). Some long-term effects of uninformed conceptual change. Science Education, 76(2), 175–197. doi:10.1002/sce.3730760206

Guzzetti, B. J., Williams, W. O., Skeels, S. A., & Wu, S. M. (1997). Influence of Text Structure on Learning Counterintuitive Physics Concepts. Journal of Research in Science Teaching, 34(7), 701–719. doi:10.1002/(SICI)1098–2736(199709)34:7 < 701::AID-TEA3 > 3.0.CO;2-Q

Hadenfeldt, J. C., Neumann, K., Bernholt, S., Liu, X., & Parchmann, I. (2016). Students' progression in understanding the matter concept. Journal of Research in Science Teaching, 53(5), 683–708. doi:10.1002/tea.21312

Hashweh, M. (1988). Descriptive studies of students' conceptions in science. Journal of Research in Science Teaching, 25(2), 121–134. doi:10.1002/tea.3660250204

Havu-Nuutinen, S. (2005). Examining Young Children's Conceptual Change Process in Floating and Sinking from a Social Constructivist Perspective. International Journal of Science Education, 27 (3), 259–279. doi:10.1080/0950069042000243736

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. Journal of Research in Science Teaching, 24(4), 291–307. doi:10.1002/tea.3660240404

Heddy, B. C., & Sinatra, G. M. (2013). Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. Science Education, 97(5), 723–744. doi:10.1002/sce.21072

Herakleioti, E., & Pantidos, P. (2016). The Contribution of the Human Body in Young Children's Explanations about Shadow Formation. Research in Science Education, 46(1), 21–42. doi:10.1007/s11165-014-9458-2

Hewson, M. G., & Hewson, P. W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. Journal of Research in Science Teaching, 20(8), 731–743. doi:10.1002/tea.3660200804

Hewson, P. W., & Hewson, M. G. A. B. (1988). An Appropriate Conception of Teaching Science: A View from Studies of Science Learning. Science Education, 72(5), 597–614. doi:10.1002/sce.3730720506

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., Blomker, K. B., Meyer, H., Lemberger, J., … Toolin, R. (1999). Educating prospective teachers of biology: Introduction and research methods. Science Education, 83(3), 247–273. doi:10.1002/(SICI)1098-237X(199905)83:3 < 247::AID-SCE1 > 3.0.CO;2-C

Hovardas, T., & Korfiatis, K. J. (2006). Word associations as a tool for assessing conceptual change in science education. Learning and Instruction, 16(5), 416–432. doi:10.1016/j.learninstruc.2006.09.003

Howe, C., Devine, A., & Tavares, J. T. (2013). Supporting Conceptual Change in School Science: A Possible Role for Tacit Understanding. International Journal of Science Education, 35(5), 864–883. doi:10.1080/09500693.2011.585353

Howe, C. J., Tolmie, A., Anderson, A., & Mackenzie, M. (1992). Conceptual knowledge in physics: The role of group interaction in computer-supported teaching. Learning and Instruction, 2(3), 161–183. doi:10.1016/0959-4752(92)90007–9

Hsu, Y.-S. (2008). Learning about seasons in a technologically enhanced environment: The impact of teacher-guided and student-centred instructional approaches on the process of students' conceptual change. Science Education, 92(2), 320–344. doi:10.1002/sce.20242

Hsu, Y.-S., & Thomas, R. A. (2002). The Impacts of a Web-Aided Instructional Simulation on Science Learning. International Journal of Science Education, 24(9), 955–979. doi:10.1080/09500690110095258

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and Learning about Force with a Representational Focus: Pedagogy and Teacher Change. Research in Science Education, 40 (1), 5–28. doi:10.1007/s11165-009-9154-9

Hulland, C., & Munby, H. (1994). Science, stories, and sense-making: A comparison of qualitative data from a wetlands unit. Science Education, 78(2), 117–136. doi:10.1002/sce.3730780202

Hynd, C., Alvermann, D., & Qian, G. (1997). Preservice elementary school teachers' conceptual change about projectile motion: Refutation text, demonstration, affective factors, and relevance. Science Education, 81(1), 1–27. doi:10.1002/(SICI)1098-237X(199701)81:1 < 1::AID-SCE1 > 3.0.CO;2-M

Hynd, C. R., McWhorter, J. Y., Phares, V. L., & Suttles, C. W. (1994). The role of instructional variables in conceptual change in high school physics topics. Journal of Research in Science Teaching, 31 (9), 933–946. doi:10.1002/tea.3660310908

Ibanez-Orcajo, M. T., & Martinez-Aznar, M. M. (2007). Solving Problems in Genetics, Part III: Change in the View of the Nature of Science. International Journal of Science Education, 29(6), 747–769. doi:10.1080/09500690600855369

Jensen, M. S., & Finley, F. N. (1995). Teaching evolution using historical arguments in a conceptual change strategy. Science Education, 79(2), 147–166. doi:10.1002/sce.3730790203

Johnson, P. (2005). The Development of Children's Concept of a Substance: A Longitudinal Study of Interaction Between Curriculum and Learning. Research in Science Education, 35(1), 41–61. doi:10.1007/s11165-004-3432-3

Johnston, A., Southerland, S. A., & Sowell, S. (2006). Dissatisfied with the Fruitfulness of 'Learning Ecologies'. Science Education, 90(5), 907–911. doi:10.1002/sce.20161

Kalkanis, G., Hadzidaki, P., & Stavrou, D. (2003). An instructional model for a radical conceptual change towards quantum mechanics concepts. Science Education, 87(2), 257–280. doi:10.1002/sce.10033

Kang, S., Scharmann, L. C., & Noh, T. (2004). Re-Examining the Role of Cognitive Conflict in Science Concept Learning. Research in Science Education, 34(1), 71–96. doi:10.1023/B:RISE.0000021001.77568.b3

Kang, S., Scharmann, L. C., Noh, T., & Koh, H. (2005). The Influence of Students' Cognitive and Motivational Variables in Respect of Cognitive Conflict and Conceptual Change. Research Report. International Journal of Science Education, 27(9), 1037–1058. doi:10.1080/09500690500038553

Kelly, G. J. (1997). Research Traditions in Comparative Context: A Philosophical Challenge To Radical Constructivism. Science Education, 81(3), 355–375. doi:10.1002/(SICI)1098-237X(199705)81:3 < 355::AID-SCE6 > 3.0.CO;2-D

Kelsey, E. (1991). Conceptual Change and Killer Whales: Constructing Ecological Values for Animals at the Vancouver Aquarium. International Journal of Science Education, 13(5), 551–559. doi:10.1080/0950069910130506

Keselman, A., Kaufman, D. R., Kramer, S., & Patel, V. L. (2007). Fostering conceptual change and critical reasoning about HIV and AIDS. Journal of Research in Science Teaching, 44(6), 844–863. doi:10.1002/tea.20173

Kwon, Y.-J., & Lawson, A. E. (2000). Linking brain growth with the development of scientific reasoning ability and conceptual change during adolescence. Journal of Research in Science Teaching, 37(1), 44–62. doi:10.1002/(SICI)1098–2736(200001)37:1 < 44::AID-TEA4 > 3.0.CO;2-J

Larsson, Å., & Halldén, O. (2010). A structural view on the emergence of a conception: Conceptual change as a radical reconstruction of contexts. Science Education, 94(4), 640–664. doi:10.1002/sce.20377

Larsson, C., & Tibell, L. A. (2015). Challenging Students' Intuitions–The Influence of a Tangible Model of Virus Assembly on Students' Conceptual Reasoning about the Process of Self-Assembly. Research in Science Education, 45(5), 663–690. doi:10.1007/s11165-014-9446-6

Lautrey, J., & Mazens, K. (2004). Is children's naive knowledge consistent? A comparison of the concepts of sound and heat. Learning and Instruction, 14(4), 399–423. doi:10.1016/j.learninstruc.2004.06.011

Lawson, A. E. (1988). The acquisition of biological knowledge during childhood: Cognitive conflict or tabula rasa? Journal of Research in Science Teaching, 25(3), 185–199. doi:10.1002/tea.3660250304

Lawson, A. E. (2003). The Nature and Development of Hypothetico-Predictive Argumentation with Implications for Science Teaching. International Journal of Science Education, 25(11), 1387–1408. doi:10.1080/09500690320000052117

Lawson, A. E., Baker, W. P., DiDonato, L., Verdi, M. P., & Johnson, M. A. (1993). The role of hypothetico-deductive reasoning and physical analogues of molecular interactions in conceptual change. Journal of Research in Science Teaching, 30(9), 1073–1085. doi:10.1002/tea.3660300906

Lee, C.-Q., & She, H.-C. (2010). Facilitating Students' Conceptual Change and Scientific Reasoning Involving the Unit of Combustion. Research in Science Education, 40(4), 479–504. doi:10.1007/s11165-009-9130-4

Lee, G., & Byun, T. (2012). An Explanation for the Difficulty of Leading Conceptual Change Using a Counterintuitive Demonstration: The Relationship between Cognitive Conflict and Responses. Research in Science Education, 42(5), 943–965. doi:10.1007/s11165-011-9234-5

Lee, G., Kwon, J., Park, S.-S., Kim, J.-W., Kwon, H.-G., & Park, H.-K. (2003). Development of an Instrument for Measuring Cognitive Conflict in Secondary-Level Science Classes. Journal of Research in Science Teaching, 40(6), 585–603. doi:10.1002/tea.10099

Lee, Y., & Law, N. (2001). Explorations in Promoting Conceptual Change in Electrical Concepts via Ontological Category Shift. International Journal of Science Education, 23(2), 111–149. doi:10.1080/095006901750039862

Lehrer, R., & Schauble, L. (2012). Seeding Evolutionary Thinking by Engaging Children in Modelling Its Foundations. Science Education, 96(4), 701–724. doi:10.1002/sce.20475

Leppavirta, J. (2012). The Effect of Naive Ideas on Students' Reasoning about Electricity and Magnetism. Research in Science Education, 42(4), 753–767. doi:10.1007/s11165-011-9224-7

Leuchter, M., Saalbach, H., & Hardy, I. (2014). Designing Science Learning in the First Years of Schooling. An Intervention Study with Sequenced Learning Material on the Topic of 'Floating and Sinking'. International Journal of Science Education, 36(10), 1751–1771. doi:10.1080/09500693.2013.878482

Lijnse, P. L. (1995). 'Developmental research' as a way to an empirically based 'didactical structure' of science. Science Education, 79(2), 189–199. doi:10.1002/sce.3730790205

Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. Learning and Instruction, 11(4–5), 357–380. doi:10.1016/S0959-4752(00)00037–2

Lin, J.-Y. (2007). Responses to Anomalous Data Obtained from Repeatable Experiments in the Laboratory. Journal of Research in Science Teaching, 44(3), 506–528. doi:10.1002/tea.20125

Linder, C. J. (1993). A challenge to conceptual change. Science Education, 77(3), 293–300. doi:10.1002/sce.3730770304

Linder, C. J. (1994). A Response to Rankin's Comment. Science Education, 78(3), 321–322. doi:10.1002/sce.3730780312

Liu, X. (2004). Using Concept Mapping for Assessing and Promoting Relational Conceptual Change in Science. Science Education, 88(3), 373–396. doi:10.1002/sce.10127

Lombardi, D., Danielson, R. W., & Young, N. (2016). A plausible connection: Models examining the relations between evaluation, plausibility, and the refutation text effect. Learning and Instruction, 44, 74–86. doi:10.1016/j.learninstruc.2016.03.003

Lombardi, D., Sinatra, G. M., & Nussbaum, E. M. (2013). Plausibility reappraisals and shifts in middle school students' climate change conceptions. Learning and Instruction, 27, 50–62. doi:10.1016/j.learninstruc.2013.03.001

Lonning, R. A. (1993). Effect of cooperative learning strategies on student verbal interactions and achievement during conceptual change instruction in 10th grade general science. Journal of Research in Science Teaching, 30(9), 1087–1101. doi:10.1002/tea.3660300907

Loving, C. C., & Foster, A. (2000). The religion-in-the-science-classroom issue: Seeking graduate student conceptual change. Science Education, 84(4), 445–468. doi:10.1002/1098-237X(200,007)84:4 < 445::AID-SCE2 > 3.0.CO;2–6

Loyens, S. M. M., Jones, S. H., Mikkers, J., & van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. Learning and Instruction, 38, 34–42. doi:10.1016/j.learninstruc.2015.03.002

MacBeth, D. (2000). On an actual apparatus for conceptual change. Science Education, 84(2), 228–264. doi:10.1002/(SICI)1098-237X(200003)84:2 < 228::AID-SCE6 > 3.0.CO;2–3

Malandrakis, G. N. (2006). Learning Pathways in Environmental Science Education: The Case of Hazardous Household Items. International Journal of Science Education, 28(14), 1627–1645. doi:10.1080/09500690600560738

Markham, K. M., Mintzes, J. J., & Jones, M. G. (1994). The concept map as a research and evaluation tool: Further evidence of validity. Journal of Research in Science Teaching, 31(1), 91–101. doi:10.1002/tea.3660310109

Martinez-Borreguero, G., Perez-Rodriguez, A. L., Suero-Lopez, M. I., & Pardo-Fernandez, P. J. (2013). Detection of Misconceptions about Colour and an Experimentally Tested Proposal to Combat Them. International Journal of Science Education, 35(8), 1299–1324. doi:10.1080/09500693.2013.770936

Mason, L. (2001). Introducing talk and writing for conceptual change: A classroom study. Learning and Instruction, 11(4–5), 305–329. doi:10.1016/S0959-4752(00)00035–9

Mbajiorgu, N. M., Ezechi, N. G., & Idoko, E. C. (2007). Addressing non-scientific presuppositions in genetics using a conceptual change strategy. Science Education, 91(3), 419–438. doi:10.1002/sce.20202

Mikkilä-Erdmann, M. (2001). Improving conceptual change concerning photosynthesis through text design. Learning and Instruction, 11(3), 241–257. doi:10.1016/S0959-4752(00)00041–4

Miller, B. W., Anderson, R. C., Morris, J., Lin, T.-J., Jadallah, M., & Sun, J. (2014). The effects of reading to prepare for argumentative discussion on cognitive engagement and conceptual growth. Learning and Instruction, 33, 67–80. doi:10.1016/j.learninstruc.2014.04.003

Mills, R., Tomas, L., & Lewthwaite, B. (2016). Learning in Earth and Space Science: A Review of Conceptual Change Instructional Approaches. International Journal of Science Education, 38 (5), 767–790. doi:10.1080/09500693.2016.1154227

Morrison, J. A., & Lederman, N. G. (2003). Science Teachers' Diagnosis and Understanding of Students' Preconceptions. Science Education, 87(6), 849–867. doi:10.1002/sce.10092

Muller, D. A., Sharma, M. D., & Reimann, P. (2008). Raising cognitive load with linear multimedia to promote conceptual change. Science Education, 92(2), 278–296. doi:10.1002/sce.20244

Muthukrishna, N., Carnine, D., Grossen, B., & Miller, S. (1993). Children's alternative frameworks: Should they be directly addressed in science instruction? Journal of Research in Science Teaching, 30(3), 233–248. doi:10.1002/tea.3660300303

Mutonyi, H., Nashon, S., & Nielsen, W. S. (2010). Perceptual Influence of Ugandan Biology Students' Understanding of HIV/AIDS. Research in Science Education, 40(4), 573–588. doi:10.1007/s11165-009-9134-0

Navarro, M. (2014). Evolutionary Maps: A New Model for the Analysis of Conceptual Development, with Application to the Diurnal Cycle. International Journal of Science Education, 36(8), 1231–1261. doi:10.1080/09500693.2013.855343

Niaz, M. (1995). Cognitive conflict as a teaching strategy in solving chemistry problems: A dialectic-constructivist perspective. Journal of Research in Science Teaching, 32(9), 959–970. doi:10.1002/tea.3660320907

Niaz, M. (2002). Facilitating Conceptual Change in Students' Understanding of Electrochemistry. International Journal of Science Education, 24(4), 425–439. doi:10.1080/09500690110074044

Niaz, M., Aguilera, D., Maza, A., & Liendo, G. (2002). Arguments, Contradictions, Resistances, and Conceptual Change in Students' Understanding of Atomic Structure. Science Education, 86 (4), 505–525. doi:10.1002/sce.10035

Nieswandt, M. (2001). Problems and possibilities for learning in an introductory chemistry course from a conceptual change perspective. Science Education, 85(2), 158–179. doi:10.1002/1098-237X(200103)85:2 < 158::AID-SCE40 > 3.0.CO;2–3

Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual change in limited or inappropriate propositional hierarchies leading to empowerment of learners. Science Education, 86(4), 548–571. doi:10.1002/sce.10032

Nussbaum, E. M., Sinatra, G. M., & Poliquin, A. (2008). Role of Epistemic Beliefs and Scientific Argumentation in Science Learning. International Journal of Science Education, 30(15), 1977–1999. doi:10.1080/09500690701545919

Oliva, J. M. (2003). The Structural Coherence of Students' Conceptions in Mechanics and Conceptual Change. International Journal of Science Education, 25(5), 539–561. doi:10.1080/09500690210163242

Österlind, K. (2005). Concept Formation in Environmental Education: 14-Year Olds' Work on the Intensified Greenhouse Effect and the Depletion of the Ozone Layer. Research Report. International Journal of Science Education, 27(8), 891–908. doi:10.1080/09500690500038264

Palmer, D. (2005). A Motivational View of Constructivist-Informed Teaching. International Journal of Science Education, 27(15), 1853–1881. doi:10.1080/09500690500339654

Palmer, D. H. (2003). Investigating the Relationship Between Refutational Text and Conceptual Change. Science Education, 87(5), 663–684. doi:10.1002/sce.1056

Palmer, D. H., & Flanagan, R. B. (1997). Readiness to change the conception that 'motion-implies-force': A comparison of 12-year-old and 16-year-old students. Science Education, 81(3), 317–331. doi:10.1002/(SICI)1098-237X(199706)81:3 < 317::AID-SCE4 > 3.0.CO;2-G

Park, H. J. (2007). Components of Conceptual Ecologies. Research in Science Education, 37(2), 217–237. doi:10.1007/s11165-006-9023-8

Park, J. (2006). Modelling Analysis of Students' Processes of Generating Scientific Explanatory Hypotheses. International Journal of Science Education, 28(5), 469–489. doi:10.1080/09500690500404540

Parker, J. (2006). Exploring the Impact of Varying Degrees of Cognitive Conflict in the Generation of Both Subject and Pedagogical Knowledge as Primary Trainee Teachers Learn about Shadow Formation. International Journal of Science Education, 28(13), 1545–1577. doi:10.1080/09500690600780179

Pearsall, N. R., Skipper, J. E. J., & Mintzes, J. J. (1997). Knowledge restructuring in the life sciences: A longitudinal study of conceptual change in biology. Science Education, 81(2), 193–215. doi:10.1002/(SICI)1098-237X(199704)81:2 < 193::AID-SCE5 > 3.0.CO;2-A

Penttinen, M., Anto, E., & Mikkilä-Erdmann, M. (2013). Conceptual Change, Text Comprehension and Eye Movements during Reading. Research in Science Education, 43(4), 1407–1434. doi:10.1007/s11165-012-9313-2

Pinarbasi, T., Canpolat, N., Bayrakceken, S., & Geban, O. (2006). An Investigation of Effectiveness of Conceptual Change Text-Oriented Instruction on Students' Understanding of Solution Concepts. Research in Science Education, 36(4), 313–335. doi:10.1007/s11165-005-9003-4

Piquette, J. S., & Heikkinen, H. W. (2005). Strategies Reported Used by Instructors to Address Student Alternate Conceptions in Chemical Equilibrium. Journal of Research in Science Teaching, 42 (10), 1112–1134. doi:10.1002/tea.20091

Pocoví, M. C. (2007). The Effects of a History-Based Instructional Material on the Students' Understanding of Field Lines. Journal of Research in Science Teaching, 44(1), 107–132. doi:10.1002/tea.20175

Posner, G. J., & Gertzog, W. A. (1982). The Clinical Interview and the Measurement of Conceptual Change. Science Education, 66(2), 195–209. doi:10.1002/sce.3730660206

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: Towards a Theory of Conceptual Change. Science Education, 66(2), 211–227. doi:10.1002/sce.3730660207

Potvin, P., & Cyr, G. (2017). Towards a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about buoyancy from preschoolers to science teachers. Journal of Research in Science Teaching, 54(9), 1121–1142. doi:10.1002/tea.21396

Potvin, P., Mercier, J., Charland, P., & Riopel, M. (2012). Does Classroom Explicitation of Initial Conceptions Favour Conceptual Change or Is It Counter-Productive? Research in Science Education, 42(3), 401–414. doi:10.1007/s11165-010-9203-4

Potvin, P., Sauriol, É., & Riopel, M. (2015). Experimental evidence of the superiority of the prevalence model of conceptual change over the classical models and repetition. Journal of Research in Science Teaching, 52(8), 1082–1108. doi:10.1002/tea.21235

Pugh, K. J., Linnenbrink-Garcia, L., Koskey, K. L. K., Stewart, V. C., & Manzey, C. (2010). Motivation, learning, and transformative experience: A study of deep engagement in science. Science Education, 94(1), 1–28. doi:10.1002/sce.20344

Rankin, G. (1994). 'A challenge to conceptual change': Comment. Science Education, 78(3), 317–320. doi:10.1002/sce.3730780311

Ravanis, K., Christidou, V., & Hatzinikita, V. (2013). Enhancing Conceptual Change in Preschool Children's Representations of Light: A Sociocognitive Approach. Research in Science Education, 43(6), 2257–2276. doi:10.1007/s11165-013-9356-z

Reiner, M., & Eilam, B. (2001). Conceptual Classroom Environment–A System View of Learning. International Journal of Science Education, 23(6), 551–568. doi:10.1080/095006901300172458

Riemeier, T., & Gropengiesser, H. (2008). On the Roots of Difficulties in Learning about Cell Division: Process-Based Analysis of Students' Conceptual Development in Teaching Experiments. International Journal of Science Education, 30(7), 923–939. doi:10.1080/09500690701294716

Roschelle, J. (1998). Beyond Romantic versus Sceptic: A Microanalysis of Conceptual Change in Kinematics. International Journal of Science Education, 20(9), 1025–1042. doi:10.1080/0950069980200902

Roth, W.-M. (1998). Learning Process Studies: Examples From Physics. International Journal of Science Education, 20(9), 1019–1024. doi:10.1080/0950069982009101

Sadler, P. M. (1998). Psychometric models of student conceptions in science: Reconciling qualitatitve studies and distractor-driven assessment instruments. Journal of Research in Science Teaching, 35(3), 265–296. doi:10.1002/(SICI)1098–2736(199,803)35:3 < 265::AID-TEA3 > 3.0.CO;2-P

Sanger, M. J., & Greenbowe, T. J. (2000). Addressing Student Misconceptions Concerning Electron Flow in Aqueous Solutions with Instruction Including Computer Animations and Conceptual Change Strategies. International Journal of Science Education, 22(5), 521–537. doi:10.1080/095006900289769

Savinainen, A., Scott, P., & Viiri, J. (2005). Using a Bridging Representation and Social Interactions to Foster Conceptual Change: Designing and Evaluating an Instructional Sequence for Newton's Third Law. Science Education, 89(2), 175–195. doi:10.1002/sce.20037

Schwendimann, B. A., & Linn, M. C. (2016). Comparing two forms of concept map critique activities to facilitate knowledge integration processes in evolution education. Journal of Research in Science Teaching, 53(1), 70–94. doi:10.1002/tea.21244

Sequeira, M., & Leite, L. (1991). Alternate Conceptions and History of Science in Physics Teacher Education. Science Education, 75(1), 45–56. doi:10.1002/sce.3730750105

She, H.-C. (2002). Concepts of a Higher Hierarchical Level Require More Dual Situated Learning Events for Conceptual Change: A Study of Air Pressure and Buoyancy. International Journal of Science Education, 24(9), 981–996. doi:10.1080/09500690110098895

She, H.-C. (2004a). Facilitating Changes in Ninth Grade Students' Understanding of Dissolution and Diffusion through DSLM Instruction. Research in Science Education, 34(4), 503–525. doi:10.1007/s11165-004-3888-1

She, H.-C. (2004b). Fostering radical conceptual change through Dual-Situated Learning Model. Journal of Research in Science Teaching, 41(2), 142–164. doi:10.1002/tea.10130

She, H.-C., & Liao, Y.-W. (2010). Bridging scientific reasoning and conceptual change through adaptive web-based learning. Journal of Research in Science Teaching, 47(1), 91–119. doi:10.1002/tea.20309

Shen, J., & Confrey, J. (2007). From conceptual change to transformative modelling: A case study of an elementary teacher in learning astronomy. Science Education, 91(6), 948–966. doi:10.1002/sce.20224

Shiland, T. W. (1997). Quantum Mechanics and Conceptual Change in High School Chemistry Textbooks. Journal of Research in Science Teaching, 34(5), 535–545. doi:10.1002/(SICI)1098–2736(199,705)34:5 < 535::AID-TEA7 > 3.0.CO;2-R

Shuell, T. J. (1987). Cognitive Psychology and Conceptual Change: Implications for Teaching Science. Science Education, 71(2), 239–250. doi:10.1002/sce.3730710210

Smith, C. L., & Wiser, M. (2015). On the importance of epistemology–disciplinary core concept interactions in LPs. Science Education, 99(3), 417–423. doi:10.1002/sce.21166

Smith, E. L., Blakeslee, T. D., & Anderson, C. W. (1993). Teaching strategies associated with conceptual change learning in science. Journal of Research in Science Teaching, 30(2), 111–126. doi:10.1002/tea.3660300202

Songer, C. J., & Mintzes, J. J. (1994). Understanding cellular respiration: An analysis of conceptual change in college biology. Journal of Research in Science Teaching, 31(6), 621–637. doi:10.1002/tea.3660310605

Sowell, S., Johnston, A., & Southerland, S. (2007). Calling for a Focus on Where Learning Happens: A Response to Abd-El-Khalick and Akerson. Science Education, 91(1), 195–199. doi:10.1002/sce.20191

Spada, H. (1994). Conceptual change or multiple representations? Learning and Instruction, 4(1), 113–116. doi:10.1016/0959-4752(94)90021–3

Stahly, L. L., Krockover, G. H., & Shepardson, D. P. (1999). Third grade students' ideas about the lunar phases. Journal of Research in Science Teaching, 36(2), 159–177. doi:10.1002/(SICI)1098–2736(199902)36:2 < 159::AID-TEA4 > 3.0.CO;2-Y

Stavridou, H., & Solomonidou, C. (1998). Conceptual Reorganisation and the Construction of the Chemical Reaction Concept during Secondary Education. International Journal of Science Education, 20(2), 205–221. doi:10.1080/0950069980200206

Stenhouse, D. (1986). 'Conceptual Change in Science Education: Paradigms and Language-Games.'. Science Education, 70(4), 413–425. doi:10.1002/sce.3730700407

Stepans, J., Dyche, S., & Beiswenger, R. (1988). The Effect of Two Instructional Models in Bringing about a Conceptual Change in the Understanding of Science Concepts by Prospective Elementary Teachers. Science Education, 72(2), 185–195. doi:10.1002/sce.3730720207

Stofflett, R. T., & Stoddart, T. (1994). The ability to understand and use conceptual change pedagogy as a function of prior content learning experience. Journal of Research in Science Teaching, 31(1), 31–51. doi:10.1002/tea.3660310105

Taasoobshirazi, G., & Sinatra, G. M. (2011). A structural equation model of conceptual change in physics. Journal of Research in Science Teaching, 48(8), 901–918. doi:10.1002/tea.20434

Taber, K. S. (2001). Shifting Sands: A Case Study of Conceptual Development as Competition between Alternative Conceptions. International Journal of Science Education, 23(7), 731–753. doi:10.1080/09500690010006572

Tal, R. T., Dori, Y. J., & Keiny, S. (2001). Assessing Conceptual Change of Teachers Involved in STES Education and Curriculum Development–The STEMS Project Approach. International Journal of Science Education, 23(3), 247–262. doi:10.1080/095006901750066501

Tao, P.-K., & Gunstone, R. F. (1999a). Conceptual Change in Science through Collaborative Learning at the Computer. International Journal of Science Education, 21(1), 39–57. doi:10.1080/095006999290822

Tao, P.-K., & Gunstone, R. F. (1999b). The Process of Conceptual Change in Force and Motion during Computer-Supported Physics Instruction. Journal of Research in Science Teaching, 36(7), 859–882. doi:10.1002/(SICI)1098–2736(199909)36:7 < 859::AID-TEA7 > 3.0.CO;2-J

Thomas, G. P. (1999). Student Restraints to Reform: Conceptual Change Issues in Enhancing Students' Learning Processes. Research in Science Education, 29(1), 89–109. doi:10.1007/BF02461182

Thomas, G. P., & McRobbie, C. J. (2001). Using a metaphor for learning to improve students' metacognition in the chemistry classroom. Journal of Research in Science Teaching, 38(2), 222–259. doi:10.1002/1098-2736(200102)38:2 < 222::AID-TEA1004 > 3.0.CO;2-S

Thorley, N. R., & Stofflett, R. T. (1996). Representation of the Conceptual Change Model in science teacher education. Science Education, 80(3), 317–339. doi:10.1002/(SICI)1098-237X(199606)80:3 < 317::AID-SCE3 > 3.0.CO;2-H

Tiberghien, A. (1994). Modelling as a basis for analysing teaching-learning situations. Learning and Instruction, 4(1), 71–87. doi:10.1016/0959-4752(94)90019–1

Tobin, K., & Tippins, D. J. (1996). Metaphors as seeds for conceptual change and the improvement of science teaching. Science Education, 80(6), 711–730. doi:10.1002/(SICI)1098-237X(199611)80:6 < 711::AID-SCE5 > 3.0.CO;2-M

Treagust, D. F., & Duit, R. (2015). On the Significance of Conceptual Metaphors in Teaching and Learning Science: Commentary on Lancor; Niebert and Gropengiesser; and Fuchs. International Journal of Science Education, 37(5–6), 958–965. doi:10.1080/09500693.2015.1025312

Trundle, K. C., Atwood, R. K., & Christopher, J. E. (2007). A longitudinal study of conceptual change: Preservice elementary teachers' conceptions of moon phases. Journal of Research in Science Teaching, 44(2), 303–326. doi:10.1002/tea.20121

Tsai, C.-C. (2003). Using a Conflict Map as an Instructional Tool To Change Student Conceptions in Simple Series Electric-Circuits. International Journal of Science Education, 25(3), 307–327. doi:10.1080/09500690210145756

Tsaparlis, G., & Papaphotis, G. (2009). High-School Students' Conceptual Difficulties and Attempts at Conceptual Change: The Case of Basic Quantum Chemical Concepts. International Journal of Science Education, 31(7), 895–930. doi:10.1080/09500690801891908

Tseng, C.-H., Tuan, H.-L., & Chin, C.-C. (2010). Investigating the Influence of Motivational Factors on Conceptual Change in a Digital Learning Context Using the Dual-Situated Learning Model. International Journal of Science Education, 32(14), 1853–1875. doi:10.1080/09500690903219156

Tsui, C.-Y., & Treagust, D. F. (2007). Understanding genetics: Analysis of secondary students' conceptual status. Journal of Research in Science Teaching, 44(2), 205–235. doi:10.1002/tea.20116

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. Science Education, 81(4), 387–404. doi:10.1002/(SICI)1098-237X(199707)81:4 < 387::AID-SCE2 > 3.0.CO;2–8

Tytler, R. (1998). Children's Conceptions of Air Pressure: Exploring the Nature of Conceptual Change. International Journal of Science Education, 20(8), 929–958. doi:10.1080/0950069980200803

Tytler, R., & Peterson, S. (2001). Deconstructing Learning in Science–Young Children's Responses to a Classroom Sequence on Evaporation. Research in Science Education, 30(4), 339–355. doi:10.1007/BF02461555

Tytler, R., & Prain, V. (2010). A Framework for Re-Thinking Learning in Science from Recent Cognitive Science Perspectives. International Journal of Science Education, 32(15), 2055–2078. doi:10.1080/09500690903334849

Ucar, S., Trundle, K. C., & Krissek, L. (2011). Inquiry-Based Instruction with Archived, Online Data: An Intervention Study with Preservice Teachers. Research in Science Education, 41(2), 261–282. doi:10.1007/s11165-009-9164-7

Venville, G. (2004). Young children learning about living things: A case study of conceptual change from ontological and social perspectives. Journal of Research in Science Teaching, 41(5), 449–480. doi:10.1002/tea.20011

Venville, G. J., & Treagust, D. F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. Journal of Research in Science Teaching, 35(9), 1031–1055. doi:10.1002/(SICI)1098–2736(199811)35:9 < 1031::AID-TEA5 > 3.0.CO;2-E

Villani, A. (1992). Conceptual Change in Science and Science Education. Science Education, 76(2), 223–237. doi:10.1002/sce.3730760209

von Aufschnaiter, C., & von Aufschnaiter, S. (2003). Theoretical Framework and Empirical Evidence of Students' Cognitive Processes in Three Dimensions of Content, Complexity, and Time. Journal of Research in Science Teaching, 40(7), 616–648. doi:10.1002/tea.10102

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. Learning and Instruction, 4(1), 45–69. doi:10.1016/0959-4752(94)90018–3

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. Learning and Instruction, 11(4–5), 381–419. doi:10.1016/S0959-4752(00)00038–4

Vosniadou, S., & Skopeliti, I. (2017). Is it the Earth that turns or the sun that goes behind the mountains? Students' misconceptions about the day/night cycle after reading a science text. International Journal of Science Education, 39(15), 2027–2051. doi:10.1080/09500693.2017.1361557

Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: Exploring conceptual change in biology. Journal of Research in Science Teaching, 27(10), 1033–1052. doi:10.1002/tea.3660271010

Watson, J. R., Prieto, T., & Dillon, J. S. (1997). Consistency of students' explanations about combustion. Science Education, 81(4), 425–443. doi:10.1002/(SICI)1098-237X(199707)81:4 < 425::AID-SCE4 > 3.0.CO;2-E

Weaver, G. C. (1998). Strategies in K-12 science instruction to promote conceptual change. Science Education, 82(4), 455–472. doi:10.1002/(SICI)1098-237X(199807)82:4 < 455::AID-SCE3 > 3.0.CO;2-A

West, L. H. T., & Pines, A. L. (1983). How 'Rational' is Rationality? Science Education, 67(1), 37–39. doi:10.1002/sce.3730670106

White, R. T. (1994). Conceptual and conceptional change. Learning and Instruction, 4(1), 117–121. doi:10.1016/0959-4752(94)90022–1

Wilson, J. M. (1998). Differences in Knowledge Networks about Acids and Bases of Year-12, Undergraduate and Postgraduate Chemistry Students. Research in Science Education, 28 (4), 429–446. doi:10.1007/BF02461508

Windschitl, M. (2001). Using Simulations in the Middle School: Does Assertiveness of Dyad Partners Influence Conceptual Change? International Journal of Science Education, 23 (1), 17–32. doi:10.1080/09500690121082

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. Journal of Research in Science Teaching, 35(2), 144–160. doi:10.1002/(SICI)1098–2736(199802) 35:2 < 145::AID-TEA5 > 3.0.CO;2-S

Wiser, M., & Amin, T. (2001). 'Is heat hot?' Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. Learning and Instruction, 11(4–5), 331–355. doi:10.1016/S0959-4752(00)00036–0

Witzig, S. B., Freyermuth, S. K., Siegel, M. A., Izci, K., & Pires, J. C. (2013). Is DNA Alive? a Study of Conceptual Change through Targeted Instruction. Research in Science Education, 43(4), 1361–1375. doi:10.1007/s11165-012-9311-4

Yen, H.-C., Tuan, H.-L., & Liao, C.-H. (2011). Investigating the Influence of Motivation on Students' Conceptual Learning Outcomes in Web-Based vs. Classroom-Based Science Teaching Contexts. Research in Science Education, 41(2), 211–224. doi:10.1007/s11165-009-9161-x

Yilmaz, D., Tekkaya, C., & Sungur, S. (2011). The Comparative Effects of Prediction/Discussion-Based Learning Cycle, Conceptual Change Text, and Traditional Instructions on Student Understanding of Genetics. International Journal of Science Education, 33(5), 607–628. doi:10.1080/09500691003657758

Yin, Y., Tomita, M. K., & Shavelson, R. J. (2014). Using Formal Embedded Formative Assessments Aligned with a Short-Term Learning Progression to Promote Conceptual Change and Achievement in Science. International Journal of Science Education, 36(4), 531–552. doi:10.1080/09500693.2013.787556

Yip, D. Y. (2001). Promoting the Development of a Conceptual Change Model of Science Instruction in Prospective Secondary Biology Teachers. International Journal of Science Education, 23(7), 755–770. doi:10.1080/09500690010016067

Zeidler, D. L. (1997). The central role of fallacious thinking in science education. Science Education, 81(4), 483–496. doi:10.1002/(SICI)1098-237X(199707)81:4 < 483::AID-SCE7 > 3.0.CO;2–8

Zietsman, A. I., & Hewson, P. W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. Journal of Research in Science Teaching, 23(1), 27–39. doi:10.1002/tea.3660230104