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Conceptual Change in Science Teaching and Learning: Introducing the Dynamic Model of Conceptual Change

Louis S. Nadelson[1], Benjamin C. Heddy[2], Suzanne Jones[3], Gita Taasoobshirazi[4], Marcus Johnson[5]

1) University of Central Arkansas
2) University of Oklahoma
3) Utah State University
4) Kennesaw State University
5) University of Cincinnati

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Louis S. Nadelson
University of Central Arkansas
Benjamin C. Heddy
University of Oklahoma
Suzanne Jones
Utah State University
Gita Taasoobshirazi
Kennesaw State University
Marcus Johnson
University of Cincinnati

Abstract

Conceptual change can be a challenging process, particularly in science education where many of the concepts are complex, controversial, or counter-intuitive. Yet, conceptual change is fundamental to science learning, which suggests science educators and science education researchers need models to effectively address and investigate conceptual change. Consideration of the current research and extant models of conceptual change reflect a need for a holistic, comprehensive, and dynamic model of conceptual change. In response, we developed the Dynamic Model of Conceptual Change (DMCC), which uses multiple lines of research that explore the variables influencing conceptual change and the dynamic interactions that take place during the conceptual change process in science teaching and learning. Unique to the DMCC is the potential for iterations, regression, enter and exit points at various stages of the conceptual change process, and the influences of message recognition, message engagement and processing, and the nature of the resulting conceptual change. The DMCC contains elements from extant models along with previously un-emphasized influential conceptual change variables such as culture, society, attitude, practices, and personal epistemology. We constructed the DMCC to provide science educators and researchers a more holistic framework for exploring conceptual change in science instruction and learning.

Keywords: Conceptual Change, Dynamic, Open System, Science Teaching and Learning

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Cambio Conceptual en la Enseñanza y Aprendizaje de Ciencias: Introduciendo el Modelo Dinámico de Cambio Conceptual

Louis S. Nadelson
University of Central Arkansas

Benjamin C. Heddy
University of Oklahoma

Suzanne Jones
Utah State University

Gita Taasoobshirazi
Kennesaw State University

Marcus Johnson
University of Cincinnati

Resumen

El cambio conceptual puede ser un proceso desafiante, particularmente en la educación de las ciencias, donde muchos de los conceptos son complejos, controvertidos o contra-intuitivos. Sin embargo, es fundamental para el aprendizaje de las ciencias, lo que sugiere que los educadores e investigadores necesitan modelos para abordar e investigarlo de manera efectiva. La investigación actual y los modelos existentes de cambio conceptual reflejan la necesidad de un modelo holístico, integral y dinámico. Desarrollamos el Modelo Dinámico de Cambio Conceptual (DMCC), que utiliza múltiples líneas de investigación que exploran las variables que influyen y las interacciones dinámicas que tienen lugar durante el proceso de cambio conceptual en la enseñanza y el aprendizaje de la ciencia. Único para el DMCC es el potencial de iteraciones, regresión, puntos de entrada y salida en varias etapas del proceso, y las influencias del reconocimiento y procesamiento de mensajes, compromiso y la naturaleza del cambio conceptual resultante. El DMCC contiene elementos de modelos existentes junto con variables influyentes de cambios conceptuales sin énfasis como la cultura, la sociedad, la actitud, las prácticas y la epistemología personal. Construimos el DMCC para proporcionar a los educadores e investigadores de ciencias un marco más holístico para explorar el cambio conceptual en la enseñanza y el aprendizaje de la ciencia.

Palabras clave: Cambio conceptual, dinámico, sistema abierto, enseñanza y aprendizaje

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Conceptual change, or the restructuring of existing knowledge, has been studied extensively in science education where students often hold incorrect or naïve conceptions about physics, chemistry, astronomy, engineering, and other scientific phenomena that conflict with what students learn in school (Sinatra, 2005). Conceptual change is particularly paramount in science education because of the many misconceptions that students develop due to intuitive thinking, everyday life experiences, movies and TV shows, and superficial science instruction (Garrison & Bentley, 1990). For decades, the research on conceptual change focused on the cognitive and developmental factors influencing changes in student knowledge. In the last 30 years, this research has shifted to consider the impact of motivation, emotions, contextual and sociocultural variables on conceptual change (Pintrich, Marx, & Boyle, 1993). Specifically, following the formalized proposal of a theory of conceptual change by Posner et al. (1982), there has been considerable research examining conceptual change and the influence of culture and society (Moje & Shepardson, 1998; Vosniadou, 1994), emotions (Gregoire, 2003), epistemological beliefs (Windschitl, 1995), motivation (Pintrich, Marx, & Boyle, 1993), and personal practices and beliefs (Chi, 2008).

Lacking in the literature is a comprehensive, holistic model that integrates the array of variables that have been empirically and theoretically linked to conceptual change. While the conceptual change models of researchers such as Gregoire (2003), Dole and Sinatra (1998), Murphy (2007), and Smith, diSessa, and Roschelle, (1994) address various influences on the process, they tend to be either contextualized (e.g. Gregoire's focus on teachers), or exclude variables that have recently been found to be associated with conceptual change. In addition, extant models of conceptual change fall short in illustrating how the array of variables linked to conceptual change may interact, how difficult it can be to illicit or maintain conceptual change, and the many ways conceptual change may or may not occur. Thus, we responded to the need for an updated, inclusive, and comprehensive model of conceptual change. Our model includes many variables linked to conceptual change in the research and does so by graphically presenting the conceptual change process as dynamic, complex, iterative, and multi-level in nature.

Before we present a new model of conceptual change, the Dynamic Model of Conceptual Change (DMCC), we offer a definition of conceptual change and explore a subset of existing conceptual change models. We provide a critique of the extant models and the potential limitations due to a growing understanding of conceptual change and the broadening of recognized variables influencing conceptual change. We then describe the processes and constructs of the DMCC and the empirical and theoretical research upon which the DMCC was developed. We close with implications for research and describe how the DMCC may be used by science education researchers to study conceptual change.

Defining Conceptual Change

Conceptual change has been defined in numerous ways. For example, from a Piagetian perspective, conceptual change involves going through a process of accommodation, a process in which schema are changed when learners are exposed to new information that does not fit with their existing conceptions (Piaget, 1970). It is important to keep in mind that in accommodation, new schemas do not supersede or supplant prior schema, as people may simultaneously hold multiple schemas to explain phenomenon (Carey, 1985; Shtulman, 2009). Rather, the new schema holds greater explanatory power or is more aligned with the experienced situation and therefore is more likely to be considered and to become the dominant conception used to explain phenomenon in a given situation or context. Thus, conceptual change is defined in ways that suggest that schema are modified (or restructured) leading to a change in conceptions or as processes of new schema formation, but yet that individuals retain their prior schemas. We take the position that conceptual change is building on an existing conception to form a new explanation while retaining explanation of the original extant conception. The result of the modification becomes the preferred conception while the original conception is retained and can still be relied up to explain phenomenon, as people may hold multiple conceptions to explain a specific phenomenon (Ohlsson, 2009; Shtulman, 2009).

Many definitions and models of conceptual change suggest that when new conceptions are formed they become dominant and prior conceptions are no longer considered, or even potentially lost (Dole & Sinatra, 1998; Posner et al., 1982). In such models, conceptions are restructured (Dole & Sinatra, 1998), resulting in newly formed conceptions that supersede prior conceptions. Other conceptual change researchers, including Vosniadou (1994) view conceptual change as the restructuring of a personal "theory" or simply a "theory change." Vosniadou argues that the change is a combination of cognitive processes of the individual and the social and environmental conditions that they experience. This perspective suggests that conceptions morph during the process of change rather than an individual developing new conceptions and retaining prior conceptions. In addition, Vosniadou recognizes the influence of society and environment on the learner and the process of conceptual change.

We contend that the process of "conceptual change" likely does not involve reconstruction of a single chunk of knowledge. Rather, we embrace the notion that learners may retain numerous conceptions of phenomenon with the ability to accurately recall and actually apply these various conceptions effectively (Smith, diSessa, & Roschelle, 1994). Thus, we support the position of Ohlsson (2009) and maintain that rather than going through a process of restructuring conceptions, learners instead adopt and form the new conceptions as their dominant conception to explain phenomenon while effectively maintaining prior conceptions in a dormant or suppressed state. Our position of learners potentially holding multiple and competing conceptions, and while it had been postulated (Carey, 1985; Ohlsson, 2009; Shtulman, 2009), the idea of multiple conceptions is not commonly emphasized in existing conceptual change models.

Challenges with Conceptual Change

The potential to simultaneously hold multiple conceptions can be used to explain the challenges with conceptual change. In knowledge acquisition, new information is learned and typically does not compete with existing conceptions. However, if a learner holds a conception and then forms a new conception of the same phenomena, the conceptions may complete or interfere with future learning and each may be reinforced by different

experiences or phenomenon – which in part can explain the challenges associated with conceptual change teaching and learning. For example, if a student holds no prior conceptions of batteries, learning how batteries work would not require the suppression of a prior conception. However, students may hold the concept that batteries are reservoirs of electrons, that get "used up" over time and then learns that batteries involve redox reactions that free up electrons that can flow in a circuit. The students' experiences with older batteries in a flashlight that is dimly lit may reinforce the reservoir conception by supporting the perception that the light is dim due to electrons in the battery being used up. Thus, when faced with having to provide an explanation of batteries, the student may rely on and apply multiple conceptions of how batteries work to explain different conditions or processes that are based on the same phenomenon.

Extant Models of Conceptual Change

In a seminal model of learners' conceptual change, Posner et al. (1982) posited the following four conditions that facilitate conceptual change: helping a learner become aware of the inadequacies in an existing conception (dissatisfaction); helping a learner find an appreciation for how a new or appropriate concept works (intelligible); persuading the learner to perceive the new concept to be a reasonable explanation of the phenomena (plausibility); and, allowing the learner to be able to apply the new concept to other areas of inquiry (fruitfulness). Yet in revisiting their early theory of conceptual change, Strike and Posner (1992) acknowledge that their initial formulation of their conceptual change theory was overly rational, falling short in taking into account factors that might be part of a learner's conceptual ecology (i.e. "motives and goals"). "Accordingly, it is proposed that the way students approach their learning would affect how they process the conflictual information and subsequent conceptual change" (Chan, Burtis, & Bereiter, 1997, p. 4).

With the emergence of the Cognitive Reconstruction of Knowledge Model (CRKM) (Dole & Sinatra, 1998), characteristics of the learner (including their motivation) and characteristics of the message are illustrated as being contributing factors in facilitating conceptual change. In the

CRKM learner characteristics interact with message characteristics in a manner that activates a level of engagement along a continuum; whereby high engagement is hypothesized to beget strong conceptual change, if any, and low engagement would beget weak or no conceptual change. It is the engagement continuum that makes the CRKM unique, because it infers that a highly engaged learner is more likely to pay attention to new information, be cognizant of inadequacies to their prior conceptions (dissatisfaction), and more active in trying to resolve cognitive conflicts. Though contemporary at the time, and more comprehensive than the conditions proposed by Strike and colleagues (1982), the CRKM has some limitations due to the lack of consideration of cultural and societal influences, learner emotions, and learner practices.

Since Dole and Sinatra's (1998) proposal of the CRKM, two additional conceptual change models have been highlighted in the contemporary educational psychology literature, including Gregoire's (2003) Cognitive-Affective Model of Conceptual Change (CAMCC) and Murphy's (2007) Belief and Knowledge Acquisition and Change Framework. Both models are in part informed by the CRKM; however, unlike the CRKM, the two models place greater emphasis on specific [social] cognitive constructs of learning, without an engagement continuum nor substantial attention to the characteristics of the message. Gregoire's CAMCC takes into account learner motivation in conjunction with whether the learner appraises a message as being a challenge or a threat. The CAMCC reflects Gregoire's (2003) assessment of teachers' reactions to the consideration of instructional reforms that challenge their existing beliefs, for which learners (in this case teachers) are presented with a message concerning a conflicting belief. In the CAMCC, Gregoire proposes that learners who appraise a message in a stressful way will eventually perceive the conflicting information as a challenge or threat to their existing beliefs. Those who appraise the information as a challenge are likely to respond with an approach intention, process the new information systematically, and perhaps experience "true conceptual change;" whereas those who appraise the new information as a threat are likely to respond with an avoidance intention, rashly process the new information, and at best experience superficial belief change, if any. The CAMCC highlights learners' affective responses to new information in

the conceptual change process. The model, however, was not meant to be a comprehensive model of conceptual change, limiting the ability to generalize or apply the model to other diverse conceptual contexts or in conjunction with other influential constructs. Regardless, the CAMCC provides justification for including affect and emotions as elements influencing the process of conceptual change.

Murphy's (2007) Belief and Knowledge Acquisition and Change Framework was the first published conceptual change model to explicitly address the hypothesized relationship between belief change and conceptual change. Murphy (2007) argues that following initial exposures to a new piece of information, learners will consider the message using either the peripheral (heuristic processing) or central route (deep cognitive processing), in alignment with dual process models of persuasion (Petty & Brinol, 2015; Petty & Cacioppo, 1986).

Through her model Murphy (2007) proposes several important implications that add to our knowledge and understanding of conceptual change. First, Murphy posits a relationship between belief change and conceptual change as a dynamic and interactive process. Related, the model also explicitly includes affect and epistemological beliefs as influential for conceptual change, which is supported by other research (Mason, Gava, & Boldrin, 2008; Patrick & Pintrich, 2001; Qian & Alverman, 2000). However, as criticism, Murphy did not include many variables in the model that are considered to be influential for conceptual change such as motivation and social/cultural contexts. The exclusion was likely intentional given the specific focus on how knowledge and belief interact during conceptual change. An additional criticism of the model is the lack of inclusion of engagement as an important factor in the change process – a variable that has been documented to be integral to conceptual change (Dole & Sinatra, 1998; Heddy & Sinatra, 2013). Regardless, while Murphy's (2007) model includes elements not present in other models (e.g. the association between belief and conceptual development) we argue that the complexity of conceptual change necessitates the inclusion of multiple variables that are absent from Murphy's (2007) model.

Taking a very different direction for explaining conceptual change, diSessa (1993) argues that individuals form fragments of knowledge that they use to develop conceptions and describe phenomenon. The fragments – labeled as phenomenological primitives or p-prims - develop based on experience and observation. While the p-prims may be useful in explaining phenomenon, a learner relying on his/her p-prims to explain concepts typically provides rudimentary and incomplete explanations of concepts. Over time, as learners gain deeper knowledge of concepts their explanation of phenomenon become more complex and comprehensive. Different from other models of conceptual change, diSessa's model suggests that conceptual change is a progressive process of gaining deeper and more complete explanations of phenomenon. Lacking from diSessa's model are the influences on conceptual change, such as motivation, culture, attitudes, and interest. Further, missing from the model is an explanation for why and how the prior conceptions are retained when new more complete explanations are formed.

Over the three decades since Posner et al.'s (1982) proposed model of conceptual change, many notable contributions have been made to the literature concerning conceptual change, many of which have highlighted components that were absent in previous models. Therefore, we are responding to the need to update the model of conceptual change so that research concerning conceptual change is consistent in its operationalization, reporting of findings, and the field of conceptual change in science education can more uniformly advance.

Elements Critical to Dynamic Model of Conceptual Change

In an effort to reconcile the limited scope of extant models of conceptual change and an increased addition of an array of variables associated with learning, we developed the Dynamic Model of Conceptual Change (DMCC). In the development of the model we took into consideration both the variables that influence conceptual change (e.g., emotions, culture) and the processes (e.g., regression to further consideration, drift from position, context of consideration) that occur. Prior to presenting the DMCC we explore the processes and constructs that influence conceptual change,

providing a justification for their inclusion in our model. We also take into consideration facets from extant models, missing elements related to conceptual change, and support from relevant empirical studies on learning.

Elements Retained from Previous Conceptual Change Models

Motivation. Motivation is an integral component when considering factors that influence the conceptual change process and inarguably should be included in any conceptual change model. We argue that motivation is an expression of the autonomy of individuals in their determination to consider (or not) alterative explanations and form new conceptions. Motivation is linked to conceptual change in science learning (Hynd, Alvermann, & Qian, 1997; Jones, Howe, & Rua, 2000; Laukenmann, Bleicher, Fub, Glaser-Zikuda, Marying, & von Rhoneck, 2003; Linnenbrink & Pintrich; 2002; Taasoobshirazi & Sinatra, 2011; Taasoobshirazi, Heddy, Bailey, & Farley, 2016; Weaver, 1998). The specific components of motivation we considered in our conceptual change model that are aligned with self- determined decision making to engage in conceptual change processes are personal relevance (Heddy & Sinatra, 2013; Sinatra, 2005), task-value (Johnson & Sinatra, 2013; Pintrich, Marx, & Boyle, 1993), and goal orientation (Johnson & Sinatra, 2014; Linnenbrink & Pintrich, 2002). However, operationally defining and considering the multifaceted nature of motivation is essential when investigating this construct (Murphy & Alexander, 2000).

In the DMCC we operationalized motivation to be the determination to take action to engage cognitively, emotionally and behaviorally in conceptual change processes. Influencing the motivation and subsequent determination to engage are personal perceptions of: 1) relevance, 2) task-value, and 3) learning goals. Personal relevance is associated with individual determination of the relatedness of learning content to their personal interest (Petty, Cacioppo, & Goldman, 1981; Pintrich, Marx, & Boyle, 1993). Thus, in the conceptual change process individuals may learn about a topic such as climate change, and recognize that they are interested in the topic and that they find it personally relevant, which can impact their

determination to engage in exploring the concepts. This engagement, according to Sinatra (2005), increases the likelihood of conceptual change.

Task-value refers to learners' perceptions of the interest, relatedness, usefulness, and cost of a task, which influences their motivation (Bong, 2004; Eccles & Wigfield, 2002). There are currently four classifications of task-value, which include intrinsic value (e.g. interest), attainment value (e.g. identity related), utility value (e.g. usefulness), and cost (e.g. effort that the task takes; Eccles & Wigfield, 2002; Eccles et al., 2003; Wigfield, 1994). The more value that individuals place on a task or topic, the more likely they are to experience conceptual change (Johnson & Sinatra, 2013; Jones, Johnson, & Campbell, 2015).

We consider goal-orientation as a critical component of motivation related to conceptual change due to the possibility of providing reason for engaging (or not) in achievement related tasks (Braten & Strømsø, 2004; Pintrich, 2000). Goal orientation is historically broken into two categories including mastery and performance goals (Ames, 1984; Dweck, 1986; Nicholls, 1984). Mastery goals involve engaging in a task in order to become competent or master a skill. In contrast, performance goals are outcome focused, normative in nature, and individuals compare themselves to others. A mastery goal mindset is aligned with a propensity for conceptual change to a greater degree than a performance approach mindset (Johnson & Sinatra, 2014; Linnenbrink & Pintrich, 2002). We contend that having a combination of mastery and performance approaches leads to greater levels of determination to engage and higher levels of motivation for conceptual change (Pintrich, Conley, & Kempler, 2003; Senko, Hulleman, & Harackiewicz, 2011).

We recognize that motivation is an incredibly complex and multifaceted construct and includes many more components than the three that we have specified in the DMCC because of the association with learner autonomy and determination to engage in conceptual change processes. We chose to focus on these aspects of motivation because each has been documented in research on conceptual change in science learning (Lavigne, Vallerand, & Miquelon, 2007). We recognize that other components of motivation such as intrinsic/extrinsic motivation, self-efficacy, and test anxiety may be

considered and examined to understand their contribution to conceptual change in science.

Cognitive Engagement. Engagement is typically defined as being comprised of cognitive, behavioral, and affective dimensions (Fredricks, Blumenfeld, & Paris, 2004). However, most of the research on conceptual change has focused on the cognitive aspect of engagement, with little examination of the affective and behavioral components of conceptual change.

Within the conceptual change process represented in our model, we operationalize cognitive engagement as occurring when individuals explicitly interpret, interact with, process, and make sense of a message. Deep cognitive engagement results in greater propensity for conceptual change than shallow cognitive engagement (Dole & Sinatra, 1998; Greene, Dillon, &, Crynes, 2003). In deep cognitive engagement the learner puts significant time and attention toward processing information about the main principles and underlying concepts; shallow cognitive engagement is typified by rote processing and simple memorization of content (Greene, Dillon, & Crynes, 2003). Cognitive engagement is a mediator between emotions and achievement (Linnenbrink & Pintrich, 2002;; Pekrun & Linnenbrink-Garcia, 2012) as well as a mediating variable between motivation and conceptual change in science learning (Taasoobshirazi, Heddy, Bailey, & Farley, 2016). In addition, deep cognitive engagement is associated with motivation and a mastery goal mindset (Meece, Blumenfeld, & Hoyle, 1988; Walker, Greene, & Mansell, 2006). Thus, there is warrant for retaining cognitive engagement when modeling conceptual change.

Extant Knowledge. In alignment with the CRKM, we recognize that the prior knowledge that learners hold influences their interpretation and engagement in processing messages (Dole & Sinatra 1998; Hewson & Hewson, 1983). However, we also contend that extant knowledge influences how learners approach conceptual change, as extant knowledge may enhance or hinder the commitment to conceptual change and the extent to which learners embrace and apply new conceptions. Extant knowledge

may undermine the adoption of new conceptions and therefore, may result in tenuous adoption of new conceptions or outright rejection of concepts. We argue that extant knowledge (or perceived understanding of phenomenon) may result in a desire to retain current conceptions regardless of accuracy, hindering the change process. Regardless of the level, extant knowledge influences conceptual change and needs to be component of related models.

Emotion. Emotion is an important factor that is highly influential on learning and motivation (Pekrun & Linnenbrink-Garcia, 2012; Pekrun, 2006; Pekrun & Stephens, 2012). We define emotion as a feeling that occurs when individuals label their psychophysiological arousal based on their evaluation of a stimuli (Pekrun, Goetz, Titz, & Perry, 2002). Emotions have a positive (joy, pride) or negative (anger, hopelessness) valence (Schutz & Pekrun, 2007). Further, emotions can be activating in that they cause physiological arousal (anger, joy) or deactivating (boredom, relief) in that they cause non-arousal (Pekrun, Goetz, Frenzel, Barchfeld, Perry, 2011; Pekrun & Perry, 2014). Depending on the valence and activating nature of the emotion, a subsequent and differential impact on conceptual change may occur. For instance, positive activating emotions, in the form of enjoyment, have shown to increase the likelihood and strength of conceptual change (Broughton, Sinatra, & Nussbaum, 2013; Heddy & Sinatra, 2013). Related, evidence exists which suggests that a decrease in negative emotions can be influential in conceptual change (Heddy, Sinatra, Danielson, & Graham, 2017).

Although several models discuss the impact that affect can have on conceptual change (Dole & Sinatra, 1998; Gregoire, 2003; Murphy, 2007), these models refer to affect, rather than emotion. Strong evidence exists supporting the relationship between conceptual change and emotion and we represent that in our model by separating emotion from other elements of affect and describing its unique predictive power on the conceptual change process.

Gregoire (2003) argues, emotional responses are triggered prior to engaging with the message and "as part of the appraisal process, serve as additional information for individuals as they interact with a complex, stressful message" (p. 168). Gregoire postulates that negative emotions are likely to promote engaging in systematic, deep processing of the message,

while positive emotions may lead to shallow engagement with processing of the message. While the CAMCC (Gregoire, 2003) conflicts with other explanations that suggest negative emotions may impede critical thinking and metacognition (Linnenbrink & Pintrich, 2002; Pekrun & Perry, 2014), the model does attend to the influence that emotions can have on conceptual change.

An initial foray into empirically documenting the relationship between emotions and conceptual change was conducted by Broughton and colleagues (2013). An important finding from the study was that students' negative emotions could be tempered through instruction, including small group discussion and debate, thus increasing the likelihood of conceptual change. Given the evidence there is support for expanding the role that emotions play in conceptual change, which support including the construct in the DMCC.

DMCC Elements Not Included in Extant Conceptual Change Models

Epistemological beliefs. Epistemological beliefs, or beliefs about the nature of knowledge and knowing (Hofer 2000; Hofer & Pintrich, 1997; Kuhn, Cheney, & Weinstock, 2000), have been shown to influence conceptual change (Kuhn, Cheney & Weinstock, 2000; Mason & Gava, 2007). A learner may be drawn upon epistemic beliefs when presented with information that conflicts with her/his prior beliefs and is faced with grappling with the ideas to make sense of them (Sinatra, Kienhues, & Hofer, 2014; Sinatra & Mason, 2013). Conceptual change is more likely to occur among learners who hold beliefs that knowledge is complex rather than simple and information is fluid rather than static (Qian & Alvermann, 1995; Windschitl & Andre, 1998).

Holding perceptions of science knowledge as tentative is crucial to conceptual change as learners with the perception are more likely to consider new information that challenges existing knowledge (Nadelson & Sinatra, 2010; Nadelson & Viskupic, 2010; Sinatra & Mason, 2013). Young students often hold dualist epistemic beliefs related to science, including the notion that science knowledge is unchanging and true and there is only one

correct answer, which hinders their ability to distinguish between evidence and knowledge (Khishfe & Abd-El-Khalick, 2002). Similarly, young students often believe that information contained in science textbooks is absolute truth, and science knowledge is static, fixed, and transmitted by authorities (Bell & Linn, 2002; Mason & Gava, 2007; Conley et al., 2004). Such perceptions are likely to hinder the determination of young students to consider conflicting messages and therefore will likely hinder their engagement in conceptual change.

Individuals who hold the view that scientists make decisions based on empirical evidenced claims and confirmed with rational arguments may be more likely to critically consider new information that conflicts with their prior knowledge (Broughton, et al., 2013; Sinatra et al., 2014). Thus, there is justification for considering epistemic beliefs when examining conceptual change.

Attitudes. In addition to emotion, attitude is an important component to include when designing a model of concept change. Attitudes can influence cognition, affect, and behavior (Hynd, 2003; Petty & Cacioppo, 1986). Attitudes are defined as an overall evaluation of an attitude object (person, place, event, or topic), and are described as a positive or negative valence of liking or disliking (Eagly & Chaiken, 1995; Frey, 1986; Holbrook, Berent, Krosnick, Visser, & Boninger, 2005; Maio, Haddock, & Spears, 2010). Attitude has been shown to have an impact on learning and conceptual change in previous research (Broughton et al., 2013; Heddy, Sinatra, Danielson, & Graham, 2017). Specifically, research shows that our attitudes influence what kind of information we seek out and how the information is processed (Frey, 1986; Holbrook, Berent, Krosnick, Visser, & Boninger, 2005). That is, instead of perceiving incoming information objectively, humans use their attitudes as a lens to encode and interpret (and perhaps judge) information (Maio, Haddock, & Spears, 2010).

Moreover, attitudes influence the extent to which people actually remember information (Eagly, Chen, Chaiken, & Shaw-Barnes, 1999). In their exploration of the inseparability of attitude and conceptual change, Sinatra and Seyranian (2015) theorize that individuals have either accurate or inaccurate knowledge in addition to positive or negative valence attitudes. Hence, how individuals engage in the conceptual change process is based on

the valence of their attitude. For instance, if someone has a negative attitude, conceptual change is unlikely (Sinatra, Kienhous, & Hofer, 2014). Based on this prior research we argue that attitude is an essential component of conceptual change.

In our model attitude influences determination to express or activate multiple personal variables including: 1) motivation, 2) emotions, 3) personally epistemology, and 4) behavior. First, attitude directly and indirectly impacts motivation to engage in multiple stages of conceptual change from message consideration to conceptual change (Holbrook, Berent, Krosnick, Visser, & Boninger, 2005). Social influences, such as cultural norms, have been shown to impact our attitudes and thus will have a significant impact on conceptual change. Second, emotions are an expression of attitudes and evidence exists that suggest initial emotions drive attitudes (Petty & Brinol, 2015), and both will have a subsequent impact on conceptual change (Heddy, Sinatra, Danielson, & Graham, 2017). Third, personal epistemologies are essentially attitudes and beliefs related to individual's perceptions of knowledge and how learning occurs (Hofer & Pintrich, 2004; Muis, Bendixen, & Haerle, 2006), which impacts conceptual change (Taasoobshirazi & Sinatra, 2011). Fourth, attitudes impact behavior in such a way that people persist through challenges in learning and remain resilient in their engagement based on their attitude toward the topic (Frey, 1986; Koestner, Bernieri, & Zuckerman, 1992). Within each of these components, attitude influences determination to engage in message consideration, message processing, and embracing conceptual change.

Attention Allocation. Attention allocation of the learner to key segments of a message is an additional variable linked to conceptual change. Previous models of conceptual change (e.g., Dole & Sinatra, 1998) have not explicitly addressed the role of attention allocation, though researchers have used cognitive engagement as a proxy for attention allocation (Broughton et al., 2010). However, researchers have demonstrated that attention allocation is distinct and has a differential effect than engagement during conceptual change processes (Jones, Johnson, & Campbell, 2015).

Attention allocation in association with conceptual change has been documented in the refutation text literature. Refutation text begins by stating

a common misconception and then directly and explicitly refutes that misconception, followed by a coherent description of the accepted scientific viewpoint (Hynd, 2001; Mason, Gava, & Boldrin, 2008). Jones and colleagues (2015) report both task value and attention allocation had a direct effect on cognitive engagement, which in turn, predicted conceptual change. Refutation text promotion of conceptual change is attributed to the attention allocation (in working memory) of the reader to his/her misconception along with the new conception which extend beyond engagement (Ariasi & Mason, 2014; Kendeou, Walsh, Smith, & O'Brien, 2014; Kendeou & van den Broek, 2005, 2007; van den Broek & Kendeou, 2008; van den Broek, Young, Tzeng, & Linderholm, 1999). Considered together, these studies indicate that as learners allocate increased attention to a message they are likely to experience conceptual change. Thus, we argue that attention allocation is a critical construct to consider in the conceptual change process because what information the learner chooses to focus on can influence the likelihood of conceptual change occurring.

Social and Cultural influences. Social and cultural context has been largely ignored in much conceptual change literature, which is unfortunate given the significant impact that societal and cultural norms have on learning (Gay, 2002; Nadelson & Hardy, 2015; Rueda, 2010). The extant models of conceptual change that we have described have not included cultural and social influences. Hence, a critical component of the DMCC is acknowledgment of the integral impact that societal and cultural context has on the change process. Pintrich and colleagues (1993) argued that the classroom community social context must be considered when hypothesizing predictors of conceptual change. In addition, teachers and peers can greatly influence conceptual change (Beeth, 1993; Beeth & Hewson, 1999; Hewson & Thorley, 1989).

Instructors who integrate controversial and meaningful discussion in their instruction such as having students critically evaluate ideas from different cultures and societies and making judgments about ideas using evidence (Nussbaum & Sinatra, 2003) can more effectively support their students' positive attitudes, engagement, and conceptual change (e.g., Broughton, Sinatra, & Nussbaum, 2013). In addition to instruction and teacher influence, peer influences such as conformity impacts message consideration

(Hardy, 1957; Petty & Cacioppo, 1986), which could impact conceptual change.

Beyond the classroom and peer influence, other cultural and societal structures should be considered when examining conceptual change such as family, congregation, museums, community events, organizations, neighbors, and media (Kelly & Green, 1998; Taasoobshirazi et. al, 2016). While there has been some exploration of social and cultural influences on conceptual perspectives in science, there is a need for deeper examination of how changing social or cultural contexts influences determination to engage in conceptual change processes. In recognition of social and cultural influences, we have included society and culture in our model as they are essential when explaining conceptual change and provide a direction for needed research.

Behavioral and Affective Engagement. Generally, three dimensions of engagement are accepted in the literature including cognitive, behavioral, and affective (Fredricks, Blumenfeld, & Paris, 2004). In previous models, only cognitive engagement has been included (Dole & Sinatra, 1998). In our model, we recognize all three aspects of engagement as integral aspects of the conceptual change process. Given that we have described cognitive engagement, we now define behavioral and affective engagement. Behavioral engagement is viewed as the actions linked with cognitive engagement such as persistence, attention, knowledge seeking, and self-regulation (Finn & Zimmer, 2012) and is considered vital for achieving positive learning outcomes (Fredricks, Blumenfeld, & Paris, 2004). Behavioral engagement is represented in our model by behaviors, practices, and resilience. Affective engagement is defined as the level of emotional response characterized by feelings of involvement with the concept to be learned (Finn & Zimmer, 2012). Affective engagement has been shown to impact conceptual change (Broughton et al., 2013; Heddy & Sinatra, 2013). In our model, learners who thoughtfully and critically weigh new information with respect to their prior knowledge are likely to seek additional information and self-regulate their learning. We maintain that those who have a positive affect and embrace knowledge seeking behaviors

will engage deeper in learning and experience have a higher propensity for conceptual change.

The Dynamic Model of Conceptual Change

Growing awareness and understanding of the predictors of conceptual change underscore the necessity for a new comprehensive model of conceptual change. While conceptual change models such as the CRKM (Dole & Sinatra, 1998), CAMCC (Gregoire, 2003), BAKCF (Murphy, 2007), and P-Prims (diSessa, 1993) have been highly influential, a substantial amount of research has been conducted in the 20 plus years since their development. Current models are missing the influence of emotion (Broughton et al., 2013; Taasoobshirazi et al., 2016), epistemological belief (Kuhn, Cheney & Weinstock, 2000; Mason & Gava, 2007), as well as culture and society (Costa, 1995), The existing conceptual change models are recursive in nature, whereas most researchers agree that cognitive/motivational processes are non-recursive (Bronfenbrenner, 2004). Furthermore, there is evidence to suggest that conceptual change is not the supplanting of conceptions, but the suppression of coexisting conceptions amid the development of more cogent conceptual models (Shtulman, 2009; Shtulman & Valcarcel 2012).

To address the limitations of extant models of conceptual change in light of the evolving understanding of the influences on conceptual change, we designed the *Dynamic Model of Conceptual Change*. Our model development was informed by the progress of conceptual change research, posited predictive influences, and deeper understanding of the contextual or potentially situational nature of conceptual change.

The basic framework for the Dynamic Model of Conceptual Change (DMCC) is based on four essential stages: 1) the message, 2) learner recognition and consideration of the message, 3) learner engagement with processing the message, and 4) conceptual change (see Figure 1). In the DMCC, the stages of learner recognition and consideration of the message, engagement in processing the message, and conceptual change, are self-regulated by the learner and influenced by the learner's motivation, society, culture, emotions, personal epistemology, extant knowledge, attention

allocation, and personal behaviors and practices. In the DMCC we have included avenues for advancing, regressing and disengaging at each stage of the conceptual change process, again, considerations that have not be part of existing conceptual change models (See Figure 1).

Conceptual Framework for the DMCC: Self Determination

We have chosen self-determination (Ryan & Deci, 2009) as a conceptual framework for the DMCC due to the emphasis on autonomy. The perception we have of motivation and the idea of volition and independence of learners in conceptual change make self-determination a useful framework for conceptualizing the DMCC. In the development of DMCC we took into account the choices that individuals make in terms of attending to, processing, interpreting and accepting messages associated with conceptual change. We included provisions for choice to exit the conceptual change process at multiple stages, as well as recurse to prior stages in a dynamic manner, conditions which are expressive of autonomy and self-determined learning (Ryan & Deci, 2008, 2009). In our model we included both personal variables (e.g. emotions, behaviors, personal epistemology) and environmental variables (e.g. society, culture, community), which can be determined based on personal choice. Given the recognition of individual choice or autonomy in facets of level of engagement, expression of personality, and attention to external influences in the conceptual change process, the DMCC is well conceptualized through the lens of self-determination.

The DMCC as a Dynamic Model

Dynamic models are created to describe processes such as decision making, to reflect the influence of multiple inputs or components, and make predictions about outcomes (Brehmer, 1992; Gonzalez, Lerch & Lebiere, 2003), conditions that are integral to the DMCC. Dynamic models are used to describe human thinking and decision making and account for the interactions of multiple components involved (e.g. choice, judgement, recognition) and possible outcomes of reasoning, and to make predictions based on the possible paths taken in the system to come to a decision (e.g.

Gonzalez, Lerch & Lebiere, 2003). Conceptual change as reflected in the DMCC could be described through a dynamic model that is nonlinear/non-recursive with multidirectional interactions, sensitive to changes in emotion, behaviors, motivation and a host of other influences, contextual and situational as the process may be different depending on the topic or timing.

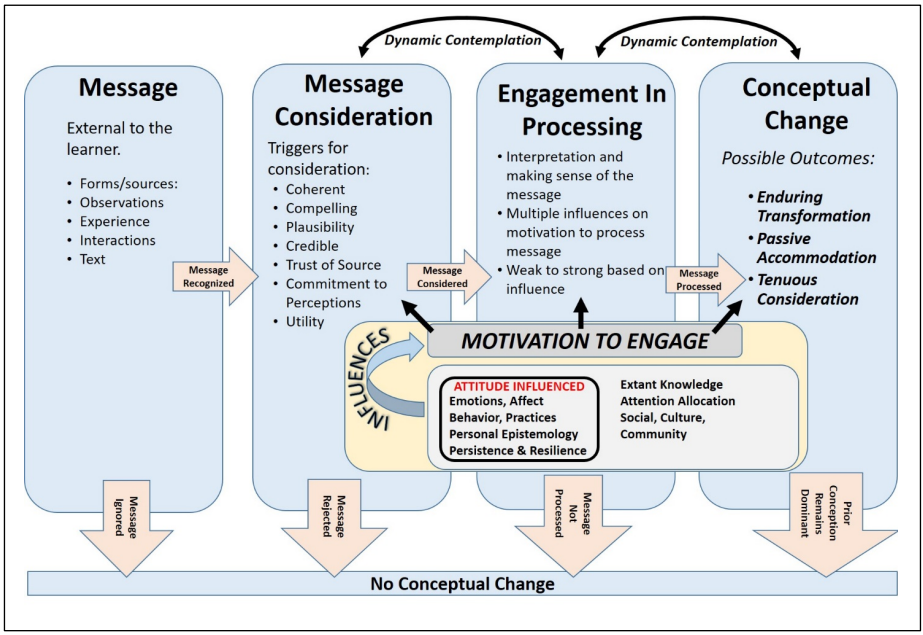

Figure 1: The Dynamic Model of Conceptual Change or DMCC.

Stage 1: The Message

In the DMCC we recognize that messages that may be considered and possibly lead to conceptual change are external to the individual. We argue that the message is not within the individual's working memory until the learner acknowledges and engages with the message. Thus, if learners disregard a message, there will be no conceptual change. Drawing from the

CRKM (Dole & Sinatra, 1998), we perceive that messages may come to the learner through observation, activities or experiences, interactions with others, or reading text.

Stage 2: Message Recognition and Consideration

Only when an individual recognizes and considers a message does the message become internal to the learner. Influences on learner consideration of and decision to process a message may be due to the source of the message, the credibility of the message, the content of the message (e.g. is the message compelling), the coherency of the message, the potential usefulness of the message, and the plausibility of the message (Lombardi, Sinatra, &, Nussbaum, 2013).

As reflected in the DMCC, we posit that learners rely on an array of personal elements that influence their consideration and engagement with a message. This includes the context in which the message is presented (Brown, Collins, and Duguid, 1989) and the learner's emotions (Pekrun, 1992), personal epistemology (Kendeou, Braasch, & Braten, 2015), prior knowledge (McNamara & Kintsch, 1996), motivation (Pintrich et al., 1993), and attention allocation (Shirey & Reynolds, 1988). In the DMCC we recognize that the extent of learner message consideration can vary from simple recognition and then disregard (resulting in no further processing and disengagement), to deep consideration (resulting in extensive engagement in message processing). If the learner does consider (and does not disregard) the message, then s/he progresses to the next stage of the DMCC - engagement with the message.

Stage 3: Engagement in Message Processing, Contemplation, and Sense Making

In the DMCC, we consider engagement as being the stage in the conceptual change process in which learners contemplate, mentally test, and attempt to make sense of a message. Again, we maintain that an array of personal and external variables influence determination to engage and contemplate with the message. Engagement in the DMCC includes cognitive, affective, and behavioral elements (Fredricks et al., 2004; Sinatra, Heddy, & Lombardi,

2015). Each dimension of engagement is suspected to overlap in such a way that assessing one dimension without also assessing the others is improbable and incomplete (Sinatra, Heddy, & Lombardi, 2015). Although the focus in conceptual change has been on the cognitive processing of messages, it is also important to consider behavioral and affective processing to make a trustworthy claim on the impact that individual engagement in the process has on conceptual change.

As with message consideration, we recognize in the DMCC the potential for varying degrees or depth of cognitive, emotional, and behavioral engagement, from long-term, deep processing to short-term shallow processing. Individuals have tremendous autonomy in their determination of their desired level of engagement. In the DMCC we recognize the interplay of the personal and external variables that influence individual motivation and determination to contemplate and explore a message in terms of value, cost, relevance and goals. If the determination is the message is of low personal value, usefulness, or does not meet individual goals the learner is likely to disengage and exit. However, if the message is of high personal value, usefulness, or does meet personal goals the learner is likely to deeply engage and transition to conceptual change.

Stage 4: Conceptual Change: Possible Outcomes

At the conceptual change stage of the DMCC, we continue to recognize the influence of the same array of personal and external elements that influence learners' determination to consider and engagement in processing the message. We propose that there is a spectrum of possible conceptual change outcomes. At one end of the spectrum is the formation of a new conception with no acceptance, resulting in a dormant conception and the retention of the original conception as dominant. In this case, the student comprehends the idea (e.g., student reads and understands a newspaper article that describes that much of global warming is a result of humans putting too much carbon in the atmosphere), but does not accept or agree with the idea (e.g., evidence does not complement their strongly held political beliefs or their personal experiences) (e.g., Lombardi & Sinatra, 2012). There is formation of a new conception as the information was processed, but the conception is dormant and the original conception remains dominant.

At the other end of the spectrum, enduring transformation, learners "understand, accept, and actively commit" to the new concept. At this level of conceptual change, the learner understands the new concept, accepts the premises of the concept and is so actively committed to the idea such that there are changes in life style, behaviors and actions (e.g. understands and accepts climate change and begins to take steps to lower carbon footprint through conservation activities).

Between the two extremes of the spectrum, but closer to "understanding and no acceptance," is tenuous consideration, which includes outcomes such as understanding, acceptance, and tenuous commitment. In these cases, a learner may understand and accept a new idea, but that acceptance is constricted resulting in fragile or tenuous commitment to the new conception. As a result, an individual with tenuous commitment will not likely be resilient or resistant to the possible consideration of conflicting messages or with time regress to her/his original conception (e.g. initially understands and accepts the idea of human induced climate change but may switch back to original misconception when faced with conflicting information or with the passing of time). Thus, individuals with tenuous commitment are unlikely to adopt changes in behaviors or find value in the new conception. Further, the tenuous commitment is likely to be subject to partial consideration or heuristic application.

More toward the "active commitment" end of the conceptual change spectrum is passive accommodation, which includes the possible outcomes of understanding, acceptance, and commitment, in which a student accepts and is committed to a conception, but this conceptual change does not translate to notable changes in behavior (e.g., understanding and fully agreeing that a large part of climate change is human induced, but not making changes to one's lifestyle such as recycling or carpooling) (Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2012). At this level, the conceptual change is more stable over time and less susceptible to be disregarded in place of original conceptions.

Dynamic Paths and Exit Points

We expect that students can move from a less (or more) committed level of conceptual change to a more (or less) committed level due to time, instruction, and/or, the array of personal factors that also influence message consideration and engagement (Carey, 1985). Thus, in the DMCC we have included a dynamic path to cycle back and forth between stages in the process of engaging in message recognition, consideration, processing, and acceptance. We have also provided pathways for disengagement at each stage of the DMCC in recognition that individuals based on the array of personal and external influences on determine they are not interested in engaging in message recognition, consideration, processing, and acceptance.

Empirically Studying the DMCC

Components of the theoretical DMCC should continue to be empirically studied. In order to study conceptual change, we first need to ensure that we have valid and reliable methods for measuring the variables implicated in contributing to conceptual change. There are valid, reliable, and widely used instruments for assessing many of the variables in the DMCC including motivation (e.g., Glynn et al., 2007; Pintrich, Smith, Garcia, & McKeachie, 1993), emotions (Broughton et al., 2013; Pekrun et al., 2011), epistemic beliefs (e.g., Schommer-Aikins, Duell, & Hutter, 2005; Schraw, Bendixen, & Dunkle, 2002), persistence (Miller, Greene, Montalvo, Ravindran & Nichols, 1996), academic buoyancy (Martin & Marsh, 2007), and resilience (Duckworth & Quinn, 2009).

Other variables in the model may need to be assessed using researcher developed items (e.g., extant knowledge, attention allocation), or instruments may exist that need some refinement before use. For example, engagement is a major component of the DMCC, however, there have been concerns regarding the validity of the most widely used instrument used to assess engagement (e.g., the Approaches to Learning Instrument, Greene, Miller, Crowson, Duke, & Akey, 2004). One main concern regarding the instrument is that it only assesses cognitive engagement, which is only one component of engagement (Greene, 2015). Engagement is hypothesized to have three components including cognitive, affective, and behavioral (Fredricks, Blumenfeld, & Paris, 2004). The Approach to Learning

Instrument should be revised to consider all three aspects of engagement that are considered in the DMCC. Similarly, other extant instruments may need to be modified to effectively gather the data necessary to empirically document the DMCC. We encourage researchers to continue to develop, validate, and psychometrically assess tools to measure the variables of conceptual change included in the DMCC. In addition, we recognize the value in refining existing instruments to effectively measure conceptual change as predicted by the DMCC.

There are advanced statistical multivariate, nested, and growth modeling techniques available today and data analysis software (e.g., Mplus, R, AMOS) make complex and dynamic model analysis relatively easy to conduct and interpret. We encourage researchers to consider these methods and tools to test how personal and external variables described in the DMCC interact to influence conceptual change.

There are a variety of methods and approaches to analysis that could be leveraged to explore the predictive properties and accuracy of the DMCC as a mode for conceptual change. Researchers have already begun to use structural equation modeling to examine how various conceptual change variables interact directly and indirectly to result in conceptual change in science (Jones, et al., 2015). The structure equation models may be used to determine which variables in the DMCC might be most or least influential or predictive of engagement and outcomes of the conceptual change process. To examine and understand how the DMCC aligns with how conceptions change over time researchers should consider growth models. Researchers seeking to examine how the DMCC predicts conceptual change for different types of students depending on their social and instructional context might rely on hierarchically structured data, or nested data analysis. Cluster analysis may be used to determine how various profiles of students are accounted for by the DMCC. To gain a deeper understanding about the influence of the variables in the DMCC and how they interact during conceptual change researchers could conduct comprehensive, qualitative interviews (Patton, 2002). Using a mixed methods approach would likely provide a detailed picture of how the DMCC pathways and variable structures interact during conceptual change. Fruitful research examining

the DMCC may involve the use of concept maps, exploratory factor analysis, confirmatory factor analysis, item response theory, and Rasch modeling. Regardless of the method or approach, empirically supporting the DMCC will lead to creative approaches to examining the interplay of variables during conceptual change.

Suggestions for Future Research

We urge researchers to use the DMCC to holistically comprehend and assess conceptual change. In the development of the DMCC we examined more than 30 years of theoretical and empirical work on conceptual change and the numerous research studies that support or refute components of the extant conceptual change models. For example, there is clear evidence that motivation (Pintrich, Marx, & Boyle, 1993), personal relevance (Heddy & Sinatra, 2013), and plausibility (Lombardi & Sinatra, 2013) impact conceptual change. In contrast, studies on need for cognition and engagement (Heddy & Sinatra, 2013; Taasoobshirazi & Sinatra, 2011; Taasoobshirazi et al., 2016) have produced mixed results suggesting complex interactions with other variables or a need for more refined research tools and methods.

Empirical tests of the DMCC, which provide exhaustive examination of the variables implicated in contributing to conceptual change, can help researchers determine which variables are most influential on conceptual change when multiple variables are under consideration. Furthermore, motivation is an umbrella term that includes multiple sub-constructs (Glynn et al., 2007, 2011). Exploring how each of these sub-constructs impact conceptual change separately would provide a more comprehensive explanation of how motivation influences conceptual change.

One possible direction for research is examining the reasons students exit from the conceptual change process. Such a direction of research may provide insight into justification for disregarding a message or disengagement due to personal or external variables. By studying disengagement, we could gather empirical evidence for the exit points of conceptual change and the variables impacting these exits. A mixed methods approach is likely to be the most effective for examining disengagement during the conceptual change process.

We also encourage researches to study DMCC variables across different conceptual change topics and contexts. For example, students have been shown to hold misconceptions in social studies (Alongi, Heddy, & Sinatra, 2016; Limon, 2002), social and behavioral sciences (Kuhle, Barber, & Bristol, 2009; Lilienfeld, Lynn, Ruscio, & Beyerstein, 2010), mathematics (Kuncar & Breigheith, 2002), and kinesiology (Brown & Vescovi, 2012; Manini, Druger, & Ploutz-Snyder, 2005). Researchers should explore if the DMCC functions in a similar fashion across different domains, topics and contexts. Thus, the DMCC may provide the framework necessary to promote research on conceptual change when students are presented with topics of varying complexity and the potential level of perceived controversy.

Practical Implications

The DMCC illustrates conceptual change as an ongoing process, as opposed to a stationary endpoint, meaning educators can and should conceptualize the facilitation of conceptual change in a manner that is ongoing, and not a one-time exercise. A practical aspect of the DMCC is how realistic, contemporary, and inclusive it is in design; allowing for it to be applied in diverse learning environments and contexts. Conceptual change is by no means easy to facilitate or maintain, and while we have highlighted above numerous studies reporting evidence concerning successful interventions that have resulted in conceptual change, we also acknowledge that there are many exit points in the conceptual change process and potential for regression. Thus, in the DMCC there are points throughout the conceptual change process where a learner may not advance in changing their conceptual understanding of a phenomenon, and instead regress and/or disengage in the conceptual change process. Furthermore, we maintain that learners do not completely abandon their prior conceptions even when conceptual change has occurred. So, what this means for educators, is that conceptual change is not guaranteed, nor is it always an end point. Educators should not be discouraged by their initial attempts to facilitate conceptual change if it is not completely successful, and instead consider the conceptual change process as ongoing and dynamic. Learners' prior

conceptions not being lost forever even when conceptual change has occurred is potentially advantageous to educators. Teachers may consider utilizing learner retention of prior conceptions to occasionally remind learners of their previous (maybe weak) conceptions and compare them to their current (hopefully dominant/appropriate) conceptions to illustrate to their students their growth and development in learning.

Our proposal of a spectrum of conceptual change from no conceptual change (new conception formed but not accepted) to enduring transformation (understand, accept, and actively commit) should also be highlighted to practitioners and educators interested in facilitating conceptual change. For assessment and evaluation purposes, educators should consider where on the conceptual change spectrum they would like their students to reach. For some conceptual learning contexts, it may be sufficient that learners only need to reach understanding but no acceptance, particularly when working with potentially controversial topics in which pressuring students into accepting and active commitment to a conceptual understanding of a phenomenon may be perceived to be unethical.

Finally, we want to reiterate that teachers and peer influence can greatly impact conceptual change. Keeping in mind that cultural and societal influences matter, there are actions that educators can do to establish, foster, and maintain a learning environment conducive to conceptual change learning. Strike and Posner (1992) acknowledged that conceptual change is not a rational or linear process as they had initially proposed, and that learners' conceptual ecology needs consideration.

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Louis S. Nadelson is a faculty member and chair of the Department of Leadership Studies at the University of Central Arkansas.

Benjamin C. Heddy is a faculty member in the Department of Educational Psychology at the University of Oklahoma.

Suzanne Jones is a faculty member in the School of Teacher Education and Leadership at Utah State University.

Gita Taasoobshirazi is a faculty member in the Department of Statistics and Analytical Sciences at Kennesaw State University.

Marcus Johnson is a faculty member in the School of Education at the University of Cincinnati.

Contact Address: Louis S. Nadelson, Department of Leadership Studies, College of Education, University of Central Arkansas, 201 Donaghey Ave, Conway AR, 72035, USA. Email: lnadelson1@uca.edu