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# Plausibility Judgments in Conceptual Change and Epistemic Cognition

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Plausibility judgments rarely have been addressed empirically in conceptual change research. Recent research, however, suggests that these judgments may be pivotal to conceptual change about certain topics where a gap exists between what scientists and laypersons find plausible. Based on a philosophical and empirical foundation, this article presents a theoretical model of the role of plausibility judgments in conceptual change (PJCC) with implications for epistemic cognition. The PJCC moves beyond the limitations of cold cognitive processing by incorporating the warmer constructs of affect, motivation, and motivated reasoning. We review recent research in plausibility judgments that informed the PJCC's development and discuss components of the model. Of particular note is the importance of using explicit critical evaluation to reappraise plausibility judgments that may have been originally made through implicit cognitive processes. We also suggest potentially productive areas of future research based on the PJCC model.

Problems facing our society require a citizenry that can make reasoned decisions about complex issues such as climate change, genetically modified foods, stem cell research, natural energy resources, and population growth. However because of the complexities often associated with scientific findings, a gap may exist between what scientists and laypersons find *plausible*—or in short, a "plausibility gap" (Lombardi, Sinatra, & Nussbaum, 2013, p. 59). By plausibility we mean what is perceived to be potentially truthful when evaluating explanations. As an example, one consistent challenge for promoting climate change understanding is that individuals often do not find it plausible that humans can impact the climate (Lombardi & Sinatra, 2012). Evolution education researchers have shown that one barrier for accepting evolution is that some individuals do not find it plausible that complex life could have emerged from simple organisms (Kirschner & Gerhart, 2005), or that the earth is billions of years old (Laughlin, 2010). It is not just controversial issues where plausibility may play a critical role. Young children often find it implausible that a solid, such as a table, is made up of moving parts (molecules; J. Nussbaum, 1997), that the earth is spherical (Vosniadou & Brewer, 1992), or that two objects of different mass drop at the same rate (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). As educational researchers, we must explore effective methods for understanding and bridging this plausibility gap.

We define plausibility in conceptual change as a judgment of *potential truthfulness* when evaluating explanations

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(e.g., accounts of how phenomena unfold that may lead to a feeling of understanding; Braaten & Windschitl, 2011; Brewer, Chinn, & Samarapungavan, 1998).[1] For example, an astronomer may explain that the sun will not go supernova (explode) at the end of its life cycle (Cain, 2014). An individual listening to this scientific explanation may find it plausible because the astronomer is a trustworthy source and delivers the explanation in a compelling way. As with this example, explanations may not include all facets of a fully developed scientific theory; rather, individuals more commonly explain by using parts of scientific theories (Giere, 2010; Salmon, 1994). In the classroom, students who are critically evaluative of explanations may shift plausibility perceptions toward scientific claims and experience *conceptual change* about controversial and complex topics (Lombardi, Sinatra, et al., 2013). Repeated use of critical evaluation and plausibility reappraisal (i.e., reconsidering previous plausibility judgments) could also result in opportunities for what Sinatra and Chinn (2011) called *epistemic conceptual change*, or a change in students' views of the nature of knowledge and knowing.

Our motivation for writing this article is to provide a descriptive account of plausibility judgments. We also describe a testable model for how plausibility works in conceptual change to guide theory and research. At the outset, we should stress that plausibility is not the only factor that influences conceptual change (see, e.g., Dole & Sinatra, 1998); however, for certain topics (i.e., abstract and/or controversial topics with a large plausibility gap), explicit consideration of plausibility judgments may be critical for knowledge reconstruction to occur. Increasing the plausibility of a scientific explanation may not necessarily result in conceptual change in and of itself. Rather, a more plausible explanation may become a critical component by which students can reconstruct a more fully developed concept aligned with scientific understanding (Gelman, Coley, & Gottfried, 1994; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

Our overall purpose is to present a theoretical model on the role of plausibility judgments in conceptual change (PJCC) that incorporates philosophical perspectives and recent empirical research. For example, the PJCC includes the warm constructs of motivation, affect, and motivated reasoning, which have not been included in prior models. Before presenting the PJCC, we discuss prior models of plausibility. We next examine how plausibility judgments have been implicated in several broader conceptual change theoretical perspectives. Based on these views, we then discuss the PJCC and its potential implications for future research. But first we provide a working definition for plausibility judgments, and discuss related constructs that have appeared in other research literatures, to lay the groundwork for the contribution of our perspective.

[1]In our working definition we are limiting the scope of plausibility judgments to explanations based on philosophical foundations (Rescher, 1976, 2003), argumentation theory (Walton, 2004), and particular relevance to conceptual change (Dole & Sinatra, 1998). We acknowledge that plausibility judgments may be made about the quality of evidence and predictive statements, for example, but for the purposes of conceptual clarity, we are focusing our discussion to explanations.

## WORKING DEFINITION OF PLAUSIBILITY

Our definition of plausibility as a judgment of *potential truthfulness* suggests a lesser standard than truth judgments, where the latter is a near-definite "measure of whether a proposition accords with reality" (Southerland, Sinatra, & Matthews, 2001, p. 328). Rescher (1976) argued that "the 'acceptance' of a proposition as a potential truth (i.e., as plausible) is not actual *acceptance* of it at all, but a highly provisional and conditional epistemic inclination towards it, an inclination that falls far short of outright commitment" (Rescher, 1976, p. 9). Rescher (2003) also stated that plausibility is "something of a practical epistemic device" that represents a "tentative or provisional endorsement" of a presumption (p. 82), which in turn is a "tentative and provisional possession of the cognitive terrain . . . until displaced by something more evidentially substantial" (p. 84). Our perspective draws heavily upon Rescher's notion of plausibility. However, we remain agnostic on Rescher's views about truth because our perspective is not contingent upon the epistemic resolution of the nature of truth. By *potential truthfulness,* we mean a judgment that lacks full epistemic commitment because "we 'accept' plausible statements only tentatively and provisionally, subject to their proving unproblematic in our deliberations" (Rescher, 2009, p. 19). Plausibility judgments are tentative because they lack full commitment, and one reason they might lack commitment is that alternative explanations may also be plausible. For example, individuals may consider it plausible that wastewater injection associated with hydraulic fracturing (fracking) has increased the frequency of moderately sized earthquakes in Oklahoma. However, individuals may be cautious because they know that earthquakes are caused by tectonic plate motion, and so think that a naturally caused increase is also plausible.

Other constructs need to be distinguished from plausibility. We address the relationship and distinctions between plausibility and some commonly related constructs (probability, coherence, comprehensibility, credibility, and believability) in the following subsections in order to provide greater clarity for our conceptualization of the plausibility judgment (see Table 1 for a summary of this discussion).

### Plausibility and Probability

According to Rescher (1976), plausibility judgments follow one "cardinal rule . . . in cases of conflict, never make the

TABLE 1
Summary of the Similarities, Relationships, and Differences Between Plausibility and Other Constructs

| *Related Construct* | *Similarities to Plausibility* | *Relationship to Plausibility* | *Differences From Plausibility* |
|---|---|---|---|
| Probability | • Evaluations used to weigh explanations. | • Probabilistic reasoning may be employed to gauge an explanation's plausibility. | • Probabilities of all alternative explanations must sum to 1. Plausibility is an ordinal and qualitative evaluation of explanations. |
| Coherence | • Emotions play a role in both judgments. | • Evaluations of explanatory coherence rely on plausibility judgments. | • Coherence is related to corroborative alignment (degree of fit), but does not account for other source validity factors (e.g., information complexity). |
| Comprehensibility | • Both are needed to evaluate explanations. | • High comprehensibility may or may not result in greater plausibility. | |
| Credibility | • Both are judgments to evaluate the quality of an explanation's source. | | • Credibility is generally conceptualized via characteristics of an information messenger (e.g., trustworthiness), but does not account for other source validity factors (e.g., information complexity). |
| Believability | • Both terms are often used synonymously in thinking and reasoning research. | | • Believability is limited in its philosophical roots to Bayesian epistemologists through the notion of degree of belief.<br>• Believability as degree of belief contains an association with willingness to assert an idea as a source; plausibility does not require such an association. |



more plausible give way to what is less so; by all means retain the more highly plausible thesis" (p. 14). In the case of conceptual change, this rule suggests that individuals may weigh the plausibility of a novel explanation against an existing mental representation. Conceptual change might not occur *even if* the individual considers this novel explanation to be plausible, but still less plausible than an existing representation (Dole & Sinatra, 1998). However, this rule does not preclude situations where an individual may think that both a novel conception and an existing mental representation (or two competing alternatives where there is little background knowledge) are plausible. The idea that two explanations of a phenomenon could be simultaneously plausible (or implausible) makes the plausibility judgment fundamentally different from probability. In reflecting on the theoretical frameworks of Rescher (1976), E. M. Nussbaum (2011) stated that there are two appreciable distinctions between plausibility and probability: (a) "opposing propositions can both be plausible, even highly plausible, but both cannot be highly probable" and (b) "plausibility is gauged on an ordinal scale, whereas probability is gauged on an interval scale" (p. 90).

Friedman and Halpern (2001) claimed that a plausibility judgment is often a default reasoning mechanism through which probabilistic reasoning is subsumed. Individuals may evaluate the strength of arguments when probabilistic reasoning is understood and properly employed through evidentiary analysis (E. M. Nussbaum, 2011). For example, if there are only two alternative explanations about a phenomenon (e.g., current climate change is caused by humans or current climate change is caused by increasing amounts of energy from the sun), then probabilistic reasoning dictates that if one alternative (human-induced climate change) is likely, the other alternative (sun-induced climate change) must be unlikely. Thus, with probabilistic reasoning, individuals could more carefully parameterize the likelihood of the arguments. However, if probability is not used, then a plausibility judgment may be the cognitive default. Even when probabilistic reasoning is used, a host of plausible assumptions are made regarding likelihoods, representativeness, and randomness (E. M. Nussbaum, 2011).

## Plausibility and Coherence

Thagard (1989, 2006) presented the idea of explanatory coherence as the fit between evidence and explanations, as well as the fit between background knowledge and other cognitions (e.g., emotions). In his theory of explanatory coherence, Thagard (2006) claimed that individuals accept an explanation based on its degree of coherence. In the explanatory coherence model, evaluation of the connections between evidence, explanations, and emotions are related to plausibility perceptions (Ranney & Schank, 1998). However, explanatory coherence primarily concerns corroborative alignment, which is only one of many factors that influence plausibility judgments (i.e., the coherence perspective may be an incomplete characterization of plausibility because other factors, such as perceptions of source trustworthiness and message complexity, may also influence plausibility; Lombardi, Seyranian, & Sinatra, 2014). Johnson-Laird (1983) reflected this idea by saying that "coherence must be distinguished from plausibility, since a discourse may be perfectly coherent yet recount a bizarre

sequence of events" that are, therefore, implausible (p. 370).

## Plausibility and Comprehensibility

Researchers have often combined the notions of comprehensibility (sometimes called intelligibility or understandability) and plausibility (Dole, 2000; Hynd, 2001; Mayer, 1984; Posner, Strike, Hewson, & Gertzog, 1982). In our earlier work, we stated that "comprehensibility is related to the coherency and consistency of the message (i.e., is the message understandable)" (Lombardi & Sinatra, 2012, p. 204). Consequently, even if students comprehend the incoming information, they may still find the message implausible. For example, "students may comprehend some basic principles behind human-induced climate change. However, students may feel that it is implausible that human activity could influence global climate" (Lombardi & Sinatra, 2012, p. 204)[2] because they may believe that human impacts can only be local, and thus cannot influence the global climate.

Recent research by Richter and his colleagues suggested that plausibility judgments may be involved in reading comprehension (Richter, 2011; Richter & Schmid, 2010; Richter, Schroeder, & Wöhrmann, 2009; Schroeder, Richter, & Hoever, 2008). During reading, individuals monitor (either implicitly or explicitly) incoming information for consistency with other ideas in the text and background knowledge (Richter & Schmid, 2010; Schroeder et al., 2008). Plausibility judgments are one way that novel explanations are related to background knowledge, which in the case of reading comprehension, are generally an automatic cognitive monitoring process analyzing for inconsistencies between new and existing ideas (Black, Freeman, & Johnson-Laird, 1986; Richter et al., 2009). However, in certain situations, individuals may engage in explicit and purposeful cognitive elaboration to resolve inconsistencies that increase plausibility perceptions of novel explanations (Maier & Richter, 2012). Such explicit processing results in greater comprehension. This line of research suggest that the relationship between comprehensibility and plausibility may then be dynamically related, rather than linear and sequential, where comprehensibility proceeds plausibility as suggested by earlier conceptual change models (see, e.g., Dole & Sinatra, 1998; Posner et al., 1982).

## Plausibility and Credibility

Credibility, particularly the credibility of an information source, has been widely examined in social psychology research, specifically in terms of its relationship on persuasion (see, e.g., Briñol & Petty, 2009). Researchers generally conceptualize credibility as a characteristic of a messenger of information (e.g., an author). Specifically, credibility is most often expressed in terms of two factors, source expertise—a gauge of a messenger's knowledge and ability to provide accurate information—and trustworthiness—a perception about the degree of a messenger's honesty (Hovland, Janis, & Kelley, 1953; Petty & Wegener, 1998), but credibility can also include judgments related to other factors (e.g., a messenger's charisma; Whitehead, 1968). Strømsø, Bråten, and Britt (2010) suggested that trustworthiness perceptions might strongly relate to background knowledge when the topic is complex and controversial. This finding is similar to the relationship between background knowledge and plausibility perceptions, suggesting a potential relationship between credibility and plausibility (Lombardi & Sinatra, 2012). In a recent study, Lombardi et al. (2014) indeed found that individuals' perceptions about the trustworthiness of the author influenced plausibility judgments about the topic of climate change; however, other perceptions relating to the content of the message (i.e., certainty in claims) also related to plausibility perceptions. This suggests to us that credibility perceptions may act as an antecedent to plausibility judgments. However, the formation of plausibility judgments may also include other antecedent factors. We discuss the importance of credibility and its importance in our model of plausibility in more detail next.

## Plausibility and Believability

The notion of believability may correspond to what Bayesian epistemologists have called "degrees of belief, " which is a person's level of commitment to assert that something is true (Ebert & Smith, 2012; Lewis, 1986; Staffel, 2012). Unlike plausibility, which is a judgment of potential truthfulness, believability is focused on the degree to which you are committed to a particular explanation. In some learning situations (e.g., a classroom discussion in where students are supporting various arguments on a controversial socioscientific issue), individuals may demonstrate a level of commitment in justifying their plausibility judgments about a particular explanation. However, in many if not most

[2]We cite some empirical studies relating plausibility to other constructs throughout our discussion (Lombardi & Sinatra, 2012, 2013; Lombardi et al., 2014; Lombardi, Sinatra, et al., 2013). In these studies, participants rated the plausibility of scientific statements about climate change (Lombardi & Sinatra, 2012, 2013; Lombardi et al., 2014), or alternative explanations about the causes of current climate change (Lombardi, Sinatra, et al., 2013), on a Likert scale from 1 (*greatly implausible or even impossible*) to 10 (*highly plausible*). This method closely followed earlier plausibility measures developed by Connell and Keane (2004, 2006). In rating the plausibility of alternative explanations, we acknowledge that participants may not have been defining plausibility as we do (i.e., judgment of potential truthfulness of an explanation). Participants' personal definitions of plausibility may have been conflated with other notions, such as probability and believability. However, in these studies individuals would often rate two alternatives as highly plausible, which implicitly deviates from probabilistic reasoning and commitment to a belief.

learning situations, plausibility judgments are tentative and not necessarily related to commitment toward an idea. Believability bears greater similarity to probability (i.e., an explanation that has high probability—by definition—means that other alternatives are of low probability, or in the case of belief, not considered). For example, many people believe that Earth is closer to the sun in summer and find it incredible when they hear the scientific explanation; that is, Earth is actually farther from the sun during the northern hemisphere's summer (Bailey & Slater, 2003). This is not necessarily the case with plausibility, where individuals could find two or more alternative explanations to be plausible

We acknowledge that believability is a construct that has been used interchangeably with plausibility in the past (see, e.g., Elliot & Devine, 1994; Goel & Vartanian, 2011; Oakhill & Johnson-Laird, 1985; Oakhill, Johnson-Laird, & Garnham, 1989). However, we are making the distinction that explanations may be plausible without an underlying commitment, as required in the Bayesian epistemological framework for degrees of belief. We therefore view plausibility as a broad judgment, under which constructs like believability and probability may overlap under certain situation. Furthermore, unlike believability, the notion of plausibility has long been connected with perspectives in conceptual change (see, e.g., Dole & Sinatra, 1998; Pintrich, Marx, & Boyle, 1993; Posner et al., 1982), argumentation (see, e.g., E. M. Nussbaum, 2011; Walton, 2004), and source evaluation and reading comprehension (see, e.g., Britt, Richter, & Rouet, 2014; de Pereyra, Britt, Braasch, & Rouet, 2014; Johnson-Laird, 1983).

## PRIOR MODELS OF PLAUSIBILITY JUDGMENTS

Plausibility has a long history in psychological research and cognitive science. For example, Johnson-Laird and colleagues conducted reading comprehension studies in the 1970s and 80s examining the relationship of plausibility, memorability, and comprehensibility, despite, in their own words, "lacking a good theory of plausibility" (Johnson-Laird, 1983, p. 375). In his seminal work on mental models, Johnson-Laird (1983) stated that plausibility is more than how a message is constructed (e.g., how coherent a message is); rather, it is how an idea is "readily . . . construed within a temporal, causal, or intentional" mental framework (p. 377). Later in the 1980s, Collins and Michalski (1989) developed a theory of logic of plausible reasoning that focused on inferences individuals draw when responding to questions that "do not have ready answers" (p. 1). However, Collins and Michalski did not provide any insights on how individuals use plausibility judgments when faced with a novel explanation; in fact, Collins and Michalski did not even define plausibility. Our perspective on plausibility draws heavily on two prior models—one that is based on a philosophical premise (Rescher, 1976) and one that is empirically based (Connell & Keane, 2004, 2006)—because these provide a richer base on which to build a model for plausibility's role in conceptual change. The following subsections, then, provide more details on the attributes of these two prior plausibility models.

### A Philosophical Model of Plausible Reasoning

Rescher (1976) developed a model of plausible reasoning that provides a framework for conceptualizing tentative epistemic judgments. Rescher's model of plausible reasoning is relatively straightforward. As shown in Figure 1, raw data are "preprocessed" first, where an individual qualitatively evaluates incoming information based on the potential truthfulness. "Preprocessing" refers to an automatic impression and in our view is not meant to imply that no cognitive processing is involved, but that the processing is likely automatic and parallel.

Rescher (1976) maintained that initial perceptions of plausibility are a function of source trustworthiness and information quality, where an information source is "understood in a very wide sense" (i.e., including people, text, rules of logic and probability, and/or validating principles). Individuals base reliability on their experiences and in terms of questioning "how solid and trustworthy" the source is (p. 7). In this sense, solidity relates to the amount of valid information that comes from a source, with greater amounts of valid information leading to greater reliability. Trustworthiness relates to the perceptions of quality of the information that comes from a source. In other words, if a source has provided valid information in the past and/or is from an authoritative position, then the information from that source may be deemed of high quality and reliable. Rescher's selection of the term *source reliability* is somewhat problematic because reliability can imply mere consistency without probative value (Osterlind, 2010; Vogt, 2007). We consider *source validity* to be a more appropriate term, which includes what social psychologists call source credibility (an important factor in persuasive communication that closely relates to trustworthiness; Pornpitakpan, 2006).

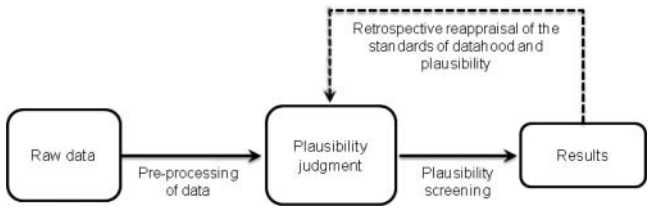


FIGURE 1 The systematic structure of plausibility analysis. From *Plausible Reasoning: An Introduction to the Theory and Practice of Plausibilistic Inference*, by N. Rescher, Amsterdam, The Netherlands: Van Gorcum, 1976, p. 118. © Nicholas Rescher. Reproduced by permission of Nicholas Rescher. Permission to reuse must be obtained from the rightsholder.

Individuals may often use validating principles to establish source validity (e.g., a simple idea had greater plausibility than a more complex idea, when other source factors are equivalent; Rescher, 1976). However, validating principles are only one component on which individuals base source trustworthiness and information quality. Plausibility perceptions may be determined primarily based on the person giving an explanation. If that person is not a trusted expert, the plausibility will be relatively low. For example, a member of Political Party A may view all information from Political Party B with low source credibility. If the Political Party A member also equates scientific claims about human-induced climate change with Political Party B claims (e.g., Political Party B supports public funding of climate science, therefore climate scientists must be members of Political Party B), then the Political Party A member could assign a lesser plausibility to any scientific ideas about climate change.

Source validity may also be based on background knowledge and personal experiences. In this way, individuals may employ heuristics when gauging plausibility, similar to those used when assessing probabilities and quantifying uncertainty. One of these is the availability heuristic, in "which people assess the . . . probability of an event by the ease with which instances or occurrences come to mind" (Tversky & Kahneman, 1974, p. 1127). For example, an individual may experience several unusual blizzards in a short period, and so when judging the plausibility of global warming may assign low source validity to messages supporting global warming because he or she will use these recent blizzards to predict long-term climate trends.

Source validity may also be based on the representativeness heuristic, "in which probabilities are evaluated by the degree . . . to which [an effect] resembles [a potential cause]" (Tversky & Kahneman, 1974, p. 1124). If a potential cause closely resembles an effect, then an individual may think that a causal relationship exists. For example, an individual may think a single record high temperature is representative of climate change because greater temperatures resemble the idea that the planet is warming over the long term. However, an individual may assign lower probability to a greater frequency of extreme events (e.g., blizzard and tornadoes) as evidence for climate change because of a lower degree of representativeness.

Rescher's (1976) plausibility model was cyclical (see Figure 1). An individual preprocesses explanations based on the validity of incoming data, which leads to a judgment about the explanation's plausibility, and then screens the plausibility of the explanation against other explanations, which results in an initial assessment of the relative truthfulness. This initial plausibility assessment can then be reappraised retrospectively, if the explanation achieves "enhanced epistemic status" (Rescher, 1976, p. 118). In other words, the explanation's validity could increase as new information is introduced, due to this *plausibility reappraisal* (i.e., reconsideration of a previous plausibility judgment). Such reappraisal may happen occasionally because plausibility judgments are characteristically tentative, without any commitment required. However, Rescher stated that an individual could explicitly and systematically reflect on the standards of their judgment (both in regards to supporting data and the initial plausibility assessment).

## A Cognitive Model of Plausibility

Connell and Keane (2004, 2006) provided a plausibility model based on cognitive mechanisms through which "some concept, scenario, or discourse is plausible if it is conceptually consistent with" other knowledge (Connell & Keane, 2006, p. 96). Connell and Keane's definition of plausibility related more directly with the idea of coherence than ours. However, Connell and Keane's detailed cognitive model has provided many insights that helped shape our conception of plausibility judgments. According to Connell and Keane, plausibility increases if an incoming idea has many "sources of corroboration" (i.e., "several distinct pieces of prior knowledge supporting any necessary inferences"). Plausibility also increases if the idea is neither a "complex explanation" (i.e., does not represent an "extended or convoluted justification") nor considered largely as "conjecture" (i.e., avoids the "introduction of hypothetical entities"; Connell & Keane, 2006, p. 99). In short, an idea "will be . . . plausible . . . if [it] . . . has minimal complexity and conjecture, and . . . maximal corroboration" (Connell & Keane, 2006, p. 99). Minimizing complexity increases plausibility. Likewise, if an individual perceives an idea as definite (i.e., unequivocal), the idea may be have higher plausibility than one that is uncertain (i.e., a conjecture). Large amounts of information that seem to support an idea may provide greater validity to an idea, and subsequently higher plausibility. For example, evolution of complex life from simpler forms may be particularly implausible for an individual because the topic has large degrees of complexity (i.e., many scientific concepts are involved, such as genetics, natural selection, and deep time) and perceived conjecture (i.e., missing transitional forms, exact common ancestors between two species are often hypothesized), and a low degree of corroboration (i.e., scientific evidence of evolution has few connections with individuals' personal experiences).

## Limitations of Prior Plausibility Models

Prior plausibility models were strongly rational and may lack direct applicability to a range of learning environments. We would classify the plausibility reasoning models of Connell and Keane (2006) and Rescher (1976) as examples of *cold cognitive processing* (Pintrich et al., 1993; Sinatra, 2005). In general, cold cognition focuses on

relationships and processing between knowledge structures (e.g., storage of knowledge in long-term memory, processing of information in working memory, attention on information, etc.), or descriptions of rational processes (logical reasoning) with little emphasis on the "warmer" constructs of affect (Brem, Ranney, & Schindel, 2003; Thagard, 2006), motivation, and social context (Sinatra, 2005) or motivated reasoning (Kunda, 1990; Taber & Lodge, 2006). Whereas Rescher acknowledged that uncomfortable feelings associated with cognitive dissonance can initiate plausibility judgments, there is virtually no mention of specific emotions, nor individuals' goals and intentions, epistemic motives and dispositions, or the social context, all which may be involved in the conceptual change process (see, e.g., Brem et al., 2003; E. M. Evans, 2001; Gregoire, 2003; Johnson & Sinatra, 2013; Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2012). However in a recent study, Lombardi and Sinatra (2013) found a significant relationship between plausibility perceptions that humans are contributing to global climate change and science educators' angry feelings about teaching climate change. The relationship was negative, where lesser plausibility perceptions were associated with greater feelings of anger. Evidence from this empirical study suggests that extrarational constructs may be dynamically and reciprocally related to plausibility judgments.

Rescher's (1976) model of plausibility reasoning also implied that individuals engage in explicit processing when making a plausibility judgment. Researchers describe explicit processing, sometimes called System 2, as cognition that is "controlled, voluntary, and effortful" (Kahneman & Klein, 2009, p. 519). On the other hand, implicit or System 1 cognitive processes are associated with automatic judgments (J. S. B. Evans & Stanovich, 2013; Kahneman & Klein, 2009). When individuals engage in System 1 thinking, they often employ the use of heuristics and act as "cognitive misers" (Stanovich, 2010). Because System 1 processes require little expenditure of cognitive resources, individuals probably make plausibility judgments implicitly. Contrary to Rescher (1976), several empirical studies support the idea that plausibility judgments are often based on implicit cognitive process. For example, in reading comprehension studies, automatic cognitive disruption (e.g., increased reading times and longer eye fixations) are related to implausible word combinations, sentences, and statements (see, e.g., Isberner & Richter, 2013; Matsuki et al., 2011; Yang, Wang, Slattery, & Rayner, 2014). Plausibility judgments also seem to automatically relate to how information is recalled from long-term memory and inferences made during situation model development (de Pereyra et al., 2014; Hinze, Slaten, Horton, Jenkins, & Rapp, 2014; Isberner & Richter, 2014). Similarly, in mathematics, a false estimation process based on implicit plausibility evaluations resulted in shorter verification times for multiplication problems with even–even and odd–odd product pairings (LeMaire & Fayol, 1995). In all of these situations, plausibility judgments probably occur with little or no explicit thought.

Richter and colleagues similarly proposed that individuals engage in plausibility judgments to minimize cognitive effort when reading (Maier & Richter, 2012; Richter, 2011; Richter & Schmid, 2010; Schroeder et al., 2008). In a study investigating the connection between construction of situation models (i.e., individuals' mental representation of what the text is about; Johnson-Laird, 1983) and epistemic validation (monitoring incoming information for consistency with other ideas in the text), Schroeder et al. (2008) found that plausibility of particular propositions was greater when these ideas readily integrated into an existing situation model. A follow-up study revealed that this tendency to base plausibility on situation model integration was reduced when participants were given a reading goal to enhance explicit elaboration (Maier & Richter, 2012). The work of Richter and his colleagues aligned with earlier research showing that implausible text is harder to comprehend than similarly structured, plausible text because readers may attempt to unconsciously "reorganize the material so that it makes better sense" (i.e., make implausible text more plausible; Black et al., 1986, p. 57). The studies, therefore, suggest that plausibility judgments are often automatic and contradict Rescher's (1976) implication of mainly explicit plausibility judgments.

Rescher's (1976) and Connell and Keane's (2004, 2006) models did not include either (a) mechanisms for both implicit and explicit processing or (b) the warmer constructs of affect, motivation, and social context, nor do these models explain conceptual change. Thus, there is a need to reconceptualize a model of plausibility in situations involving evaluation of explanations that includes these components. Critical to this model's development are some of the ideas found in conceptual change research; specifically relevant are ideas about how researchers treat plausibility in several perspectives of conceptual change.

## PLAUSIBILITY AND CONCEPTUAL CHANGE

Our definition for conceptual change—reconstruction of conceptual knowledge—is based on the philosophical underpinnings of scientific revolutions (Feyerabend, 1962; T. S. Kuhn, 1962; Laudan & Laudan, 1989; Nunan, 1988), which have been used as an analog to conceptual change (Chinn & Brewer, 1993; Posner et al., 1982), as well as psychological learning theories involving reconstruction of knowledge (Chi, 2005; Dole & Sinatra, 1998; Vosniadou & Brewer, 1992). From this perspective, conceptual change implies that an individual has an existing mental representation (e.g., proposition stored in long-term memory, schema, mental model, or naïve theory) that is inconsistent with scientific understanding. Conceptual change occurs when those types of knowledge structures are reformed to

represent scientifically accurate knowledge. Many conceptual change theorists have included plausibility judgments as a major factor in conceptual change. In the following subsections, we highlight four predominant conceptual change theories that helped us to frame our perspective on plausibility. We should note that these theories view plausibility somewhat differently than we do but build upon each other and toward our model of plausibility. We highlight some of these differences, as well as strengths and weaknesses concerning these previous conceptualizations.

### The Classic Conceptual Change Model

Posner et al. (1982) proposed that conceptual change proceeds in a linear fashion analogous to the process that occurs within scientific revolutions. First, an individual experiences dissatisfaction with an existing conception. Then the individual must find the novel conception to be intelligible and appear initially plausible. Conceptual change will occur if the new conception also "leads to new insights and discoveries" (p. 222) when applied to a broader perspective (i.e., the new conception is fruitful). Posner et al. specifically described plausibility "as the anticipated degree of fit of the new conception into an existing conceptual ecology" (p. 218) and suggested five ways in which conceptions may become initially plausible: (a) consistency with metaphysical beliefs and epistemological commitments, (b) consistency with other theories or knowledge, (c) consistency with past experiences, (d) match of the conceptual image with personal expectations, and (e) capability to resolve anomalies. Note that Posner et al. often conceptualized plausibility through the perspective of coherence (i.e., in their use of the words "consistency and matching"), which does not fully reflect our characterization of plausibility judgments (e.g., an explanation may be coherent but still implausible). Furthermore, Posner et al. did not provide a detailed model of how plausibility might influence conceptual change.

Posner et al. (1982) made several important recommendations about instructional strategies to promote conceptual change. With regard to plausibility, Posner et al. said, "Any available metaphors, models, and analogies should be used to make a new conception more intelligible and plausible" (p. 224). This idea of associating intelligibility (more commonly called message comprehensibility or understandability; see, e.g., Mayer, 1984) and plausibility is found in many subsequent discussions of conceptual change. However, our research has suggested that individuals may fully comprehend a message but still find the explanation to be implausible (Lombardi & Sinatra, 2012).

Whereas Posner et al. (1982) tended to fuse intelligibility and plausibility, as well as coherency and plausibility, their insight into the instructional use of analogies is consistent with Rescher's (1976) notion that plausibility is related to qualitative evaluations about conceptions. Clement (1993) argued that experts often use "qualitative physical intuition schemas" rather than "formal" quantitative strategies to create bridging analogies in solving problems (p. 1252). Experts' use of bridging analogies "may therefore be important plausible reasoning strategies for developing and refining physical intuitions" (Clement, 1993, p. 1252). Analogical reasoning may also promote an inference to understand a relationship between the source and target analog (Holyoak, 2005), but the analogical inference must be plausible to be effective (Kapon & diSessa, 2012). Subsequently, analogical and plausibilistic reasoning may be connected if the inference used in making an analogy is abductive in nature (i.e., inferences to the best explanation; Harman, 1965). Analogies could also enhance plausibility if the analogical information is consistent with background knowledge. In other words, analogical reasoning may increase the degree of corroboration between novel explanations and existing knowledge, which in turn could increase plausibility. Therefore, this analogical/plausible mechanism may be involved when individuals psychologically respond to explanations that conflict with their existing theories.

### Psychological Responses to Conflicting Information

Chinn and Brewer (1993) based their analysis of plausibility in accordance with Posner et al.'s (1982) classic conceptual change model and specifically looked at what happens when students experience scientific evidence that conflicts with their naïve theories. According to Chinn and Brewer, there are seven ways that students may react when they experience "anomalous data" that could potentially result in cognitive conflict or evaluation of a novel explanation. They may (a) ignore (discard data with no explanation), (b) reject (discard data with explanation), (c) exclude (place data outside the domain of their existing conception), (d) hold in abeyance (deal with the data later), (e) reinterpret (incorporate data into the domain of their existing conception), (f) modify peripherally (make a superficial change to their existing conception), or (g) reconstruct theory (undergo strong conceptual change so that their understanding is consistent with scientific knowledge).

The "availability of a plausible alternative theory" may play a role in determining which of these seven responses occurs (Chinn & Brewer, 1993, p. 15). They further argued that a new theory that accurately accounts for the anomalous data should be judged as plausible. Chinn and Brewer stated that "an essential ingredient in a plausible theory is a plausible physical *mechanism*" (p. 21). For example, the theory of biological evolution is based on the plausible physical mechanisms of random mutation and natural selection. Chinn and Brewer (2001) have found that, on a psychological level, comprehension of a physical mechanism results in greater plausibility. Brewer et al. (1998) further stated that plausibility is an important way that individuals determine the quality of an explanation (p. 122). However,

these researchers see plausibility as a degree of consistency between a novel explanation and background knowledge, which we view as only partially characterizing the role of plausibility judgments in conceptual change.

### Ontological Shift

In addition to plausible mechanisms, conceptions can be characterized via attributes that plausibly bind them within an ontological category (Chi, 2005; Chi & Roscoe, 2002). For example, anything within the *object* ontological category may plausibly have the attribute of color, even though some objects may be colorless (e.g., air). However, color would not be a plausible attribute of the *process* ontological category (e.g., melting of Antarctic ice sheets would not plausibly possess the attribute of color). Because conceptual change occurs when a student shifts a concept from one ontological category into another, plausibility plays a central role in Chi's model. In other words, for a shift to occur, the concept must be reliably consistent with the ontological attributes that the student may have assigned to that category.

The ontological perspective, along with the conceptual change theories of Posner et al. (1982) and Chinn and Brewer (1993), were established using the framework of their time, which was one of cold cognitive processing. As we have already discussed, more recent research has also included consideration of "warmer" extrarational processes, such as motivation, affect, and social context, to gain a more complete understanding of plausibility's role in conceptual change.

### Integrating Conceptual Change and Plausibility Into a Warmer Cognitive Arena

A major shift in conceptual change research occurred with a seminal article by Pintrich et al. (1993). These researchers posited that learner characteristics (e.g., motivation) and the social environment in the classroom strongly influence conceptual change. In other words, conceptual change may not necessarily be a completely rational process for individuals. Pintrich et al. viewed plausibility as a combination of consistency and relevance with background knowledge. But these researchers expanded upon this idea by proposing that when individuals seek plausibility in a new mental representation, they may undergo a deeper level of cognitive processing through elaboration and organization, which "facilitate encoding and learning" (p. 174). This is consistent with the work of LeMaire and Fayol (1995), where shorter verification times (i.e., indicating a superficial level of processing) were associated with quick implausibility judgments and longer verification times (i.e., indicating deeper processing) are associated with a more deliberate determination of plausibility. Maier and Richter (2012) also posited that explicit elaboration promotes purposeful plausibility judgments and helps learners resolve cognitive conflict or evaluate explanations.

Dole and Sinatra's (1998) cognitive reconstruction of knowledge model (CRKM) embraced the viewpoint of Pintrich et al. (1993) by postulating an interaction between the qualities of an individual's existing conceptions (i.e., strength, coherence, and commitment to the existing conception), the individual's motivation to process new information, and the incoming "message" conflicting with the individual's existing conception. Dole and Sinatra claimed that plausibility is one of four critical aspects of an incoming message, along with degrees of comprehensibility, coherence, and compelling rhetoric.

Dole and Sinatra (1998) said that when individuals make a plausibility judgment about a message, they weigh the probability of evidence by deciding on the probability of its usefulness. Probability demands that when one alternative is highly likely, the other alternative must be unlikely. This is counter to the idea of qualitatively considering two opposing alternatives to be plausible (or implausible). Unlike probability, a plausibility judgment is not necessarily an "either/or" proposition but could involve relative and ordinal ranking of alternatives, where both may be considered plausible (E. M. Nussbaum, 2011). Our model will hold to this qualitative perspective on plausibility, and therefore will deviate in this respect from how Dole and Sinatra conceptualized plausibility. However, many other elements of Dole and Sinatra's CRKM have informed our model of plausibility in conceptual change. In fact, we extend the CRKM by taking a closer look at plausibility, a construct that was not fully developed in this broader model of conceptual change.

## PLAUSIBILITY IN EPISTEMIC CONCEPTUAL CHANGE

Plausibility has received much attention in the conceptual change literature (particularly from a theoretical perspective); however, epistemic cognition research has given plausibility much less attention. There is a potential link, however, between conceptual change and epistemic cognition: To improve understanding of science, students need to reconstruct both their conceptual understanding and their epistemic cognitive processes (Sinatra & Chinn, 2011). The former—reconstruction of conceptual understanding—is conceptual change. The latter—change in the cognitive processes and beliefs involved in making judgments about knowledge and knowing—is called epistemic conceptual change (Sinatra & Chinn, 2011). The basic premise behind epistemic conceptual change is that misconceptions persist about how scientists construct knowledge, as well as the actual knowledge scientists have constructed.

Sinatra and Chinn (2011) argued that to improve understanding of science, students should reconstruct both their

conceptual understanding and their epistemic cognitive processes. In other words, "growth in epistemic cognition and reasoning may require conceptual change in the understanding of epistemic constructs such as evidence and argumentation" (Sinatra & Chinn, 2011, p. 270). Epistemic conceptual change involves transformation of students' conceptions of epistemic processes from thinking that is weakly aligned with scientific perspectives on the nature of knowledge (i.e., scientific knowledge is absolute and accumulated solely through observation and experimentation, or scientific knowledge is uncertain and subjective, and one theory may be as valid as another) to thinking that is well aligned with scientific perspectives on the nature of knowledge (e.g., scientific knowledge is constructed via scientific evaluations; Barzilai & Zohar, 2012; Bråten, Britt, Strømsø, & Rouet, 2011; King & Kitchener, 2004; D. Kuhn, 2009; Sinatra & Chinn, 2011). Essential to the development of more reflective epistemic stances are the thinking processes that provide an understanding of how various knowledge domains are justified and the use of that understanding in reasoning and problem solving (Chinn, Buckland, & Samarapungavan, 2011; Green, Azevedo, & Torney-Purta, 2008).

Epistemic cognition, however, may often involve implicit and situationally dependent thinking processes (Chinn et al., 2011; Sinatra, Kienhues, & Hofer, 2014; Weinstock, 2011). Chinn et al. (2011) have proposed that these often automatic epistemic cognition processes are interrelated and fall into five broad categories: (a) epistemic aims and values, (b) structure of epistemic accomplishments (e.g., knowledge and understanding), (c) sources and justification of epistemic accomplishments, (d) epistemic virtues and vices, and (e) processes to achieve epistemic accomplishments. Plausibility judgments may be a dynamically related outcome of these implicit epistemic cognition processes. For example, in considering sources and justification for knowledge, an individual may find a particular messenger lacks trustworthiness and expertise, and therefore the author's explanations may be implausible (Britt et al., 2014; de Pereyra et al., 2014). At the same time, an individual may develop self-constructed plausible explanations through narrative without any reference to actual evidence (D. Kuhn, 1991). In such a scenario, a layperson's personal explanation may be more plausible than a scientific explanation simply based on perceptions of credibility (e.g., an individual may not trust all scientists based on a fictional account of nefarious actions by a "mad" scientist). The potential relationships between plausibility and other epistemic cognition processes in general are beyond the scope of our discussion (for a more detailed overview of epistemic cognition, see Chinn et al. 2011; Green et al., 2008). However, in terms of epistemic conceptual change, plausibility reappraisal (i.e., reconsideration of previous plausibility judgments) may have a role in overcoming implicit and automatic cognitive judgments about knowledge. Plausibility reappraisal, in particular, could be one ingredient that helps form a scientific habit of mind (Lombardi, Sinatra, et al., 2013), although this claim is speculative because empirical support is lacking.

Higher quality plausibility judgments, therefore, may be dynamically linked to critical evaluation and facilitate epistemic conceptual change (i.e., shifting from thinking processes associated with knowledge subjectivity to evaluative processes of knowledge construction based on evidence). Specifically, by engaging in critical evaluation and plausibility reappraisal, individuals could move toward a belief that such processes help to reliably achieve an epistemic aim (e.g., greater understanding about a scientific topic; Chinn et al., 2011). However, we acknowledge that such claims are speculative and in need of empirical support.

## Model of Plausibility Judgments in Situations Involving Evaluation of Novel Explanations

Figure 2 shows our model of plausibility judgments in situations involving evaluation of novel explanations.[3] Novel explanations that conflict with background knowledge are often involved in conceptual change learning situations, and therefore, for the purposes of brevity, we are calling our conceptualization the PJCC model. Before presenting the PJCC in detail, we offer a vignette to demonstrate one possible path through the model.

## A Vignette Demonstrating the PJCC

Imagine a middle school student, Keisha, who is faced with a novel explanation of a phenomenon, such as climate change. On the Internet, Keisha read that climate change is caused by an increase of solar energy. Her teacher, during a weather and climate unit, provides the scientific explanation that current climate change is caused by human activities. According to the PJCC, Keisha is faced with a novel explanation that conflicts with what she had read earlier (Source Validity Pre-processing Box, Figure 2). Keisha implicitly preprocesses the source validity of the novel explanation from the teacher. She considers her teacher to be credible about scientific topics. Her implicit trust of the teacher's expertise would raise the initial plausibility of the incoming proposition. However, the inherent complexity in the topic lowers the source validity. Furthermore, Keisha has just been through an early spring blizzard, an unusual event in her town, leading her to a skeptical stance initiated by the availability heuristic. Keisha has also heard that

[3]A preliminary version of this model appeared in Lombardi et al., (2013). The preliminary version had some similarity to the current model with respects to the source validity preprocessing and formation of the plausibility judgment. However, both of these processes are extended and expanded upon here. Furthermore, the current model contains a major reconceptualization of the plausibility reappraisal feedback loop, as well as the potential for conceptual change outcomes.

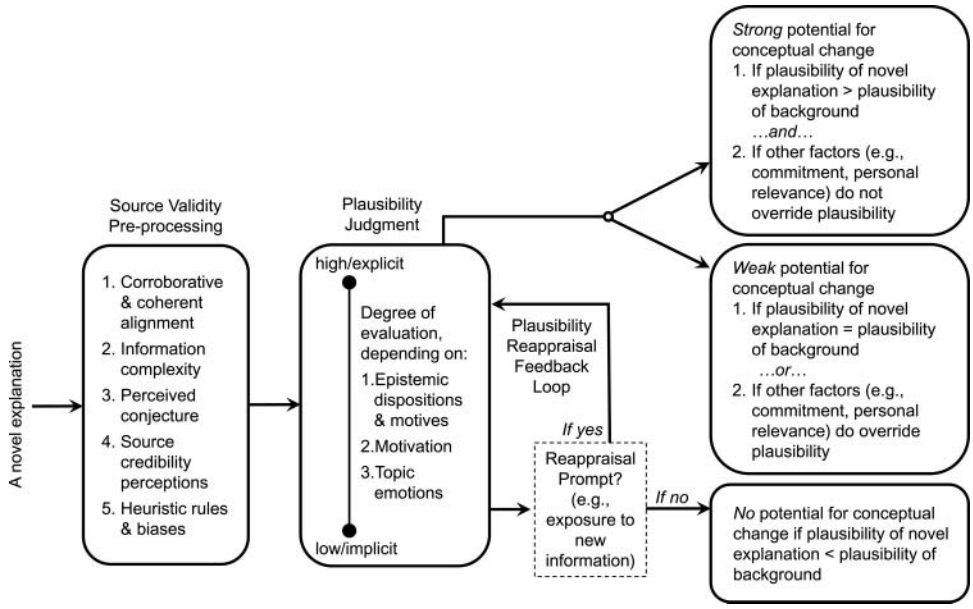


FIGURE 2 A model of the role of plausibility judgments in conceptual change.



scientists are uncertain about the degree to which humans are impacting the climate. This increases the perceived conjecture and lowers the plausibility of the teacher's message. Overall, this makes the plausibility of the teacher's explanation about humans impacting the planet lower than the explanation she read earlier on the Internet—a popular skeptics' explanation that current climate change is caused by an increase of solar energy. We speculate that not all of the screening principles need to be active in the preprocessing of novel explanations; however, they most likely involve automatic processing.

The teacher then shows an image of the "hockey stick" graph showing the recent spike in global temperatures. Keisha associates this graph with a documentary she saw on TV, *An Inconvenient Truth*. She remembers that when watching the documentary, her father said that climate change is a political creation constructed by Al Gore. Thinking about climate change as a political ploy makes her angry, and she does not evaluate the teacher's explanation deeply. She is not motivated to engage in the teacher's explanation about humans' contribution to current climate change, because she is satisfied with her current conception. Therefore, she makes an implicit plausibility judgment (see Plausibility Judgment Box, Figure 2), with the novel conception having a low plausibility. If Keisha does not engage in plausibility reappraisal, this judgment of low plausibility would mean that there would likely be no potential for conceptual change (see No Potential for Change Area, Figure 2).

The next day, the teacher leads Keisha and her classmates through an instructional activity promoting critical evaluation and plausibility reappraisal (see Plausibility Reappraisal Feedback Loop, Figure 2). During the activity, Keisha is exposed to different information when she weighs the connections between scientific evidence and the two competing explanations of climate change (human-induced and sun-induced). One piece of evidence shows that over the past 30 years solar energy has been decreasing while global temperatures have been increasing. This additional piece of information prompts her curiosity (an epistemic emotion; Pekrun, 2011) about humans' role in climate change (see Reappraisal Prompt Dashed Box, Figure 2). Keisha now has a goal to attend to the teacher's explanation about the causes of current climate change. Furthermore, she explicitly sees that evidence that refutes the sun induced model and reevaluates her initial plausibility judgment (see again, Plausibility Judgment Box, Figure 2). This explicit reappraisal leads to an increase in her plausibility perceptions of the scientific explanation. Because of the tentative nature of the plausibility judgment, reappraisal (reconsideration) can occur, perhaps repeatedly, through extended reflective inquiry. In this specific example, the plausibility of the scientific model is greater than the plausibility of her existing conception, and Keisha may experience conceptual change if other factors (e.g., lack of personal relevance) do not override her plausibility judgment (see Strong Potential for Conceptual Change Box, Figure 2). In other words, if Keisha understood the explanation and found the explanation plausible, and found the topic to be personally relevant to her and her family, conceptual change may occur. However, Keisha would experience only a weak potential for conceptual change if other factors override her plausibility judgment. For example, her teacher may say that major impacts will not occur for several decades, potentially

lowering the personal relevance of climate change (see Weak Potential for Conceptual Change Box, Figure 2).

This vignette is just one example of the role of plausibility in conceptual change and epistemic conceptual change, as depicted in the PJCC. The following subsections discuss the PJCC's components in more detail.

## Source Validity Preprocessing

Five screening principles may influence source validity preprocessing: (a) corroborative and coherent alignment of novel explanations with background knowledge, (b) complexity of the novel explanations, (c) perceived degree of conjecture or uncertainty, (d) source credibility perceptions, and (e) heuristic rules and biases (see Source Validity Preprocessing Box, Figure 2). We have just discussed these five screening principles in some detail and illustrated in our scenario how they might operate to help form plausibility judgments but offer another example to show how source validity may influence plausibility for a different topic. Biological evolution involves many scientific concepts (e.g., natural selection, random mutation, deep time) and therefore is a complex topic. Such complexity may lead to perceptions of lower source validity and contribute to a judgment of implausibility. An individual may also perceive a great amount of conjecture within the message of biological evolution because the exact common ancestry for some species is not known. Again, greater conjecture could lead to lower source validity and lower plausibility. An individual could also have limited personal experience with biological evolution and therefore lack any form of corroborative connections. In this case, the message may not make sense and the plausibility would be minimized. Finally, an individual's heuristics and biases may be activated, for example, because of the perception that biological evolution is accepted by one group that is counter to the group in which the individual is a member (i.e., the ingroup/outgroup heuristic; Tajfel & Turner, 1985). The source may therefore be deemed untrustworthy, which then may contribute to a greater degree of implausibility.

## Plausibility Judgments

Central to the PJCC is the actual plausibility judgment (see Plausibility Judgment Box, Figure 2), which may involve implicit processing (i.e., System 1, with low awareness and low cognitive effort), explicit processing (System 2, with high awareness and high cognitive effort), or in some cases both types of processing. Because of individuals' proclivity toward System 1 cognition (i.e., acting as "cognitive misers"; Stanovich, 2010), the plausibility judgment might often be implicit, as suggested by Maier and Richter (2012) and Schroeder et al. (2008). We have represented the degree to which the plausibility judgment is implicit or explicit as a continuum (i.e., the *degree of evaluation*). This degree of evaluation would depend on the plausibility judgment being based on such things as (a) skilled intuition developed through expertise in a particular domain (e.g., a theoretical physicist may be implicitly evaluative when considering the validity of new theory on subatomic particles, Kahneman & Klein, 2009), (b) individuals' dispositions to think deeply and be inclined to impartially consider alternative explanations, and (c) the social or instructional context that could promote critical evaluation.

*Epistemic dispositions and motives.* Research on epistemic dispositions and motives emerges from the social psychology literature that, in part, helped to form Dole and Sinatra's (1998) CRKM model. In particular, epistemic dispositions are associated with relatively stable personality traits relating to an individual's views about knowledge and/or its acquisition. Dole and Sinatra specifically identified need for cognition in their model, which is a disposition toward engaging deeply in topics because of enjoyment (Cacioppo, Petty, Feinstein, & Jarvis, 1996). Individuals with a high need for cognition tend to appreciate complexity and do not seek closure on an issue prematurely, and therefore may be more implicitly evaluative in making plausibility judgments. In a study involving undergraduate students, Sinatra, Southerland, McConaughy, and Demastes (2003) found "that willingness to entertain knowledge change intentionally (the central theme of the dispositional scales) affects acceptance of evolution" (p. 521). In such a case, the initial plausibility judgment could place a relatively high index on a complex and controversial novel explanation, but only if the individual has a tendency to be more explicitly evaluative.

Epistemic motives are an individual's inclination toward a particular view of knowledge, such as seeking or avoiding closure (Kruglanski, 1989). Epistemic motives may also be dispositional in that they are relatively stable for extended periods. Lombardi and Sinatra (2013) found that decisiveness (a need for closure subcomponent; Webster & Kruglanski, 1994) and anger about teaching about climate change were significant predictors of individuals' plausibility perceptions about human-induced climate change. In Lombardi and Sinatra's (2013) study, greater decisiveness predicted lower plausibility, potentially indicating that individuals with an urgent desire to decide may tend to evaluate explanations heuristically (i.e., as theorized by Dole & Sinatra, 1998). This tendency could assign a comparatively greater weight to existing mental representations, and therefore the plausibility judgment could favor background knowledge over novel explanations.

Sinatra et al. (2012) found that another need for closure subcomponent, specifically close-mindedness, was related to undergraduates' willingness to commit to actions that would mitigate climate change. Greater levels of close-mindedness predicted a lower degree of commitment to act. Although the researchers did not measure plausibility

perceptions in this study, following the PJCC, we would hypothesize that one reason for the lack of willingness may have been because the participants did not consider human-induced climate change to be plausible.

*Motivation.* Students' motivation would also influence their degree of evaluation of explanations (i.e., the degree of implicitness/explicitness in the plausibility judgment). In their conceptual change model, Dole and Sinatra (1998) described several motivational factors, including students' (a) "stake in the outcome," (b) "interest in the topic," and (c) "self-efficacy about the topic" (p. 119). These motivational factors may influence the plausibility judgment implicitly or explicitly. For instance, students with low interest in the novel explanation may have relatively low engagement and evaluation compared to explanations of greater interest. Much science education research has highlighted differences in student interest about differing topics, such as boys being more interested in physical science topics and girls being interested in life science topics (Tytler & Osborne, 2012). With such differences, boys, for example, may generally find cosmological notions of dark energy more plausible than girls do because of boys' proclivities toward greater interest in and potentially greater engagement with physical science topics. On the other hand, girls may have a relatively strong interest in topics related to health care, and therefore may find explanations of the strong relationship between biological evolution and cancer treatment as more plausible than boys do.

Research in motivation and conceptual change reveals that students' goal orientations (i.e., mastery vs. performance) interact with "awareness, knowledge, and the intentional reconstruction of knowledge" (Sinatra & Mason, 2008, p. 565). Students with a mastery orientation could provide a greater ranking toward a novel explanation even though it is anomalous because of their desire for greater mastery. Furthermore, mastery goals may result in more explicit and critical evaluation of novel explanations (Linnenbrink & Pintrich, 2002), thereby changing the plausibility judgment.

*Topic emotions.* Emotions based specifically on the topic of instruction may also influence the degree of evaluation and resulting plausibility judgment. Topic emotions may potentially interfere with motivation and cognition in a reciprocal fashion, similar to the way that general academic emotions interfere with motivation and cognition (Pekrun, Frenzel, Goetz, & Perry, 2007; Sinatra, Broughton, & Lombardi, 2014). In an overview of research on emotion in education, Linnenbrink (2007) stated that current research is converging on "the view that there are bi-directional, reciprocal relations among motivation, affect, and cognition" (p. 311). From the conceptual change perspective, an individual's feelings about a particular topic may affect the judgment of a novel explanation. Lombardi and Sinatra (2013) showed a relationship between teachers' anger about teaching about climate change, an epistemic motivation toward decisiveness, and the plausibility of human-induced climate change, with greater anger and decisiveness associated with greater implausibility. However, despite this initial evidence, the direction of the relationship between plausibility and topic emotion is still uncertain. Gregoire (2003) argued that affective appraisals, such as threat and stress, "happen automatically before characteristics of the message [e.g., plausibility] are seriously considered and that message characteristics may never be fully processed on the basis of appraisals made" (p. 168). The potential reciprocal nature of plausibility judgments and topic emotions could provide a fruitful area for future research.

## Prompt for Plausibility Reappraisal

The reappraisal prompt (see the Reappraisal Prompt Dashed Box, Figure 2) is one component of the PJCC that could represent more explicit epistemic cognition.[4] For example, plausibility reappraisal could be prompted through a classroom activity introducing new information that allows students to critically examine what they know and how they know. First, such critical comparison could facilitate knowledge reconstruction because individuals would be engaged in inquiry through "metacognitive reflection, rethinking their old beliefs and comparing them with the new ideas in order to judge the new ideas as more plausible and fruitful" (Pintrich et al., 1993, p. 174). Dole and Sinatra (1998) called this critical comparison *high metacognitive engagement*. Second, Rescher (1976) stated that when the reappraisal "happens systematically . . . we are in the position to reevaluate—and revise—the existing criteria of plausibility themselves" (Rescher, 1976, p. 118). Critical evaluation of ideas (and of epistemic criteria; Chinn et al., 2011) results in plausibility judgments based on explicit reflection (see Plausibility Judgment Box in Figure 2), which may be initiated by some reappraisal prompt. Reappraisal is akin to what Kintsch (1988) refered to as "plausibility checks," where contextually related but new information may increase an explanation's plausibility by creating a richer cognitive structure through which activation can spread.

[4]We acknowledge that other explicit epistemic cognition processes may be dynamically linked to plausibility reappraisal, and potentially other aspects of the PJCC. For example, reflective evidence evaluation, which would not necessarily be a tentative judgment that is involved in plausibility appraisal or reappraisal, may also involve explicit epistemic cognition. When students list evidence for and against a model, this may not correspond directly to the plausibility characteristic as "potential truthfulness." Plausibility reappraisal may therefore be one of a number of processes, some longer and more reflective, that involve explicit epistemic cognition. The tentative endorsement of plausibility judgments may occur iteratively, in a longer deliberative reflection (e.g., during long-term instruction).

Social interactions may be one way to prompt reappraisal of plausibility because related ideas may be introduced. Dole and Sinatra (1998) stated that "a host of social contexts," such as "students in a group discussion, may motivate students to consider new or conflicting information that they have disregarded in the past because they value their peers' viewpoints" (pp. 119–120). Relevant social interactions could also include listening to a teacher, reading a text, or watching video from a highly reliable source. These interactions could then explicitly initiate another plausibility judgment because of the tentative and provisional nature of the original appraisal. However, social interactions can also lead to rejection of new information when the group is not favorably disposed to it (Taber & Lodge, 2006), and even when the social context is favorably disposed, that may not be sufficient to create the type of sustained critical engagement and reflection necessary for plausibility reappraisal and conceptual change (Dole & Sinatra, 1998, p. 121). Therefore, epistemic conceptual change may also be required.

Well-designed instruction can facilitate explicit and reflective epistemic cognitive processes that prompt plausibility reappraisal. In a recent study, Lombardi, Sinatra, et al. (2013) found that students engaging in an activity promoting critical evaluation experienced significant changes pre- to postinstruction in their relative plausibility judgments about two models explaining current climate change: the scientifically accepted model of human-induced climate change (Doran & Zimmerman, 2009) and a skeptic model that Earth is receiving increasing amounts of energy from the sun (Cook, 2010). The instructional activity is called a model-evidence link diagram (Chinn, Duschl, Golan Duncan, Buckland, & Pluta, 2008; Lombardi, Sibley, & Carroll, 2013). Lombardi, Sinatra, et al. (2013) reported that students reappraised their initial plausibility judgments about the causes of climate change after engaging in the model-evidence link activity, whereas a comparison group did not. Furthermore, plausibility reappraisal was associated with significantly higher scores at postinstruction assessing their understanding of the fundamental principles underlying climate change, as well as demonstrated conceptual change about the causes of climate change.

Instruction facilitating critical evaluation and plausibility reappraisal may be especially important for topics where a scientific explanation may seem implausible and a nonscientific alternative explanation may seem plausible. One such situation could be where an individual considers an explanation as plausible based on "pseudoevidence [that] cannot be sharply differentiated from the [explanation] itself" (D. Kuhn, 1993, p. 324). Pseudoevidence is an explanation enhancement that may be used to increase plausibility but is not based on actual evidence. For example, a student explaining rotation rates of different-sized wheels could say, "Big wheels will go slower [than smaller wheels] because it takes more time for the wheels to go around" (D. Kuhn, 1993, p. 330). However, instruction that promotes critical evaluation (e.g., participating in argumentation discourse about the connection between evidence and explanations; Duschl & Osborne, 2002) could prompt plausibility reappraisal.

Sustained instruction in critical evaluation and plausibility reappraisal could also potentially lead to developing a scientific habit of mind in students. For example, students who possess a nonscientific epistemic stance could experience activities in an evaluative epistemic environment, and potentially develop the ability to think scientifically when confronted with scientific explanations (Bråten, Ferguson, Strømsø, & Anmarkrud, 2014). Therefore, instruction designed to promote plausibility reappraisal may be an effective pedagogical strategy for epistemic conceptual change.

### Potential for Change

The plausibility judgment would be implemented through some degree of implicit and explicit processing; however, if the plausibility of a scientifically accurate conception is not greater than that of an alternative, it is unlikely that conceptual change will result—even if other factors are conducive for change. We view this response as *potential for change*, which is based on the strength of a novel (or reappraised) explanation relative to background knowledge (Strong, Weak, and No Potential for Conceptual Change Boxes, Figure 2). When the plausibility of the novel explanation is less than that of an individual's background knowledge, the individual is more likely to retain the existing conception, and therefore there is no potential for conceptual change given those plausibility appraisals. For example, a student may have had an existing incorrect conception that the moon was formed via gravitationally captured asteroid fragments. After hearing a scientific lecture that the moon was formed when a smaller planet impacted Earth, the student was intrigued but thought the explanation to be unduly complex, and therefore implausible. Thus, the student had no potential to change their existing incorrect conception of gravitational capture.

A weak potential for change exists when the plausibility perceptions are about equal. In this case, there are factors that will "tug" an individual toward or away from change, but the potential for change is uncertain because the outcome of the plausibility judgment could go either toward or away from the new conception. To avoid cognitive dissonance, individuals might refrain from engaging with the new conception, or they might try to resolve the dissonance by searching for more information to change their plausibility perceptions (or they might change arbitrarily). Furthermore, other factors such as commitment-based social group membership could override increased plausibility (Dole & Sinatra, 1998). Considering the example of the student's moon misconception, a weak potential for conceptual

change might have occurred if the student saw a persuasive video visually showing the scientific impact theory of formation. Because of the video's persuasiveness, the plausibility of the scientific explanation may have increased so that both alternative explanations are now comparably plausible. However, a friend who also saw the video may consider scientists to be part of a greater NASA moon hoax conspiracy, prompting cognitive disengagement away from the scientific explanation.

A strong potential for conceptual change occurs when the plausibility of the novel explanation is greater than that of the alternative. In this case, the plausibility judgment in favor of the new conception would be a key factor determinative of conceptual change, and potential acceptance of the novel explanation. In other words, acceptance of a novel explanation would be a change in conception initiated by the plausibility judgment. In particular, if the plausibility judgment is explicit, acceptance of a new explanation could be based "upon a systematic evaluation of evidence" (Sinatra et al., 2003, p. 512). For example, individuals may find it believable that a preservative in some vaccinations leads to autism based on a personal story told by a celebrity. This could lead to a belief that all vaccines are potentially harmful. Such a belief is potentially related to a strong commitment to motherhood shared with the celebrity. However, by weighing the connections between scientific evidence and explanations about the efficacy of vaccinations, individuals may find it plausible that vaccines reduce disease occurrence. Continued participation in scientific argumentation could provide additional support for the idea that the benefits associated with vaccinations far outweigh the rare side effects. This example illustrates a situation where the plausibility appraisal may be more explicit and purposeful, as might happen in an instructional setting. A strong potential for conceptual change would also require that other factors not override the plausibility judgment. For example, an individual may be satisfied with his or her existing conception because of a personal stake in the outcome (Dole & Sinatra, 1998).

We see this potential for conceptual change as a continuum and not as three distinct categories. This potential for conceptual change is related but not completely analogous to Dole and Sinatra's (1998) engagement continuum, where there may be a gradual variation of "information processing, strategy use, and reflectivity" (p. 121) that individuals employ in a conceptual change learning environment. Students are unlikely to engage with implausible ideas (but there are individual differences where some students may try to understand strange ideas better). Students may or may not engage when plausibility judgments are equal. Students are most likely to engage with ideas that are perceived to have high plausibility and cognitive utility. Results from an empirical study support this idea by showing that a necessary condition for knowledge reconstruction is that the plausibility of a novel explanation supersedes the plausibility of any competing alternatives (Lombardi, Sinatra, et al., 2013).

### Relationship Between Prior Plausibility Models, Conceptual Change Models, and the PJCC

The structure of the PJCC draws from Rescher's (1976) model of plausible reasoning (see Figure 1). For example, we incorporate Rescher's preprocessing of data into what we are calling "source validity preprocessing." We also draw upon Connell and Keane's (2006) model of plausibility, as well as the literature on heuristics and biases (see, e.g., Tversky & Kahneman, 1974). We have also included the plausibility judgment but provided more details about related factors and the judgment's nature. The PJCC deviates somewhat from Rescher's idea of plausibility screening with results to what we call the "judgment result and potential for conceptual change," which we have included to provide greater clarity/specificity to how this process may work in conceptual change. We included Rescher's plausibility reappraisal loop but have modified this to include our understanding of the processes of epistemic cognition through explicit consideration of a reappraisal prompt. The PJCC has also been modified to account for conceptual change by drawing on aspects of Dole and Sinatra's (1998) CRKM, which has influenced the warming trend in conceptual change (Sinatra, 2005). The PJCC extends the CRKM by revealing how plausibility judgments may form and be reappraised through explicit cognitive processing. We also reiterate that other factors—beyond plausibility—may also be required for an individual to experience conceptual change. For example, if two competing explanations are equally plausible, then reappraisal would not be a decisive factor in whether an individual changes his or her knowledge. However, we do believe that the PJCC will provide a useful model for future research examining conceptual change situations concerning topics where a large plausibility gap exists between scientific and alterative explanations.

## DIRECTIONS FOR FUTURE RESEARCH

Recently, several studies have suggested the importance of plausibility judgments (Connell & Keane, 2004, 2006; Kapon & diSessa, 2012; Lombardi et al., 2014; Lombardi & Sinatra, 2012; Lombardi, Sinatra, et al., 2013; Maier & Richter, 2012; Schroeder et al., 2008) and critical evaluation leading to plausibility reappraisal (Chinn & Buckland, 2012; Lombardi, Sinatra, et al., 2013). Given this growing interest, conceptual change research might benefit from explicating a model of plausibility judgments when faced with novel explanations. We offer the PJCC as a guide for future research and design of learning environments. However, the PJCC is in need of further testing, and we now

discuss specific areas of research potential based on this model.

## Future Research on the PJCC

We have identified five sources of source validity preprocessing; however, there may be other factors related to source validity that researchers should identify and examine. Little research exists about how sources are evaluated during conceptual change learning, and specifically how sources contribute to the initial plausibility judgment about a novel explanation. For example, corroborative alignment may be related to the perceived trustworthiness of the information. A study by Bråten, Strømsø, and Britt (2009) showed that individuals' trustworthiness perceptions of different information sources on climate change related strongly to their comprehension. Trustworthiness as a measure of source credibility (Mason, Ariasi, & Boldrin, 2011) may influence the initial plausibility judgment, and ultimately the possibility for greater cognitive engagement with the incoming information. Despite the import of these studies, they do not directly examine the relationship between source evaluation and plausibility appraisal, which is an important next step.

Lombardi et al. (2014) recently conducted a study to examine the relationship between source validity and plausibility perceptions. In this study, perceptions of certainty in message claims and source trustworthiness were significant predictors of plausibility perceptions of climate change. Further analysis also suggested that these source validity factors were implicit antecedents to the plausibility judgment. The topic of the study was a controversial socioscientific issue (climate change), and when teaching about such topics, educators may therefore wish to promote goal-directed reading, where students specifically evaluate biases that may impact perceptions about the topic.

We also wonder how stable plausibility judgments are after critical evaluation. One area of future research could explore whether implicit plausibility reappraisals could result in the adoption of nonscientific conceptions. Evidence shows that even when individuals adopt a new conception, the original conception is maintained in memory (Shtulman & Valcarcel, 2012), suggesting that the relative plausibility of the two conceptions may be critical for maintaining the foregrounding of the scientific conception in problem solving and reasoning.

We have identified some "warm" constructs in the PJCC (i.e., epistemic dispositions and motives, motivation, and topic emotions). However, additional motivational variables should be explored in interaction with plausibility judgments. For example, Johnson and Sinatra (2013) have found that utility values (i.e., individuals' perceptions of the usefulness of a task in attaining their future goals) relate to conceptual change. Correspondingly, Chinn et al. (2011) proposed "that people will be more likely to pursue epistemic achievements that they deem to be valuable or significant" (p. 149). Individuals place greater value on knowledge and ways of thinking that help them achieve their goals and are less likely to experience conceptual change if there is no personal benefit. This raises two possibilities in terms of the plausibility judgment. On one hand, a person could perceive that a novel explanation is of low utility and therefore have little cognitive engagement with this explanation (Ohlsson, 2009). Perceptions of this novel explanation's plausibility would be lower than their existing background knowledge and the potentiality of change would be reduced in this situation. On the other hand, a person could perceive that a novel explanation is of high utility, which could increase engagement and evaluation (Ohlsson, 2009), and create a cognitive environment for increased plausibility and the potential for conceptual change. This is our speculation, of course, but research into the relationship between epistemic values and plausibility perceptions of various scientific ideas would help us understand (at least partially) how motivational variables influence "epistemic cognitions . . . from situation to situation" (Chinn et al., 2011, p. 163).

The process of intentional conceptual change may be another motivationally related construct in which plausibility plays a key role. Sinatra and Taasoobshirazi (2011) described the process of intentional conception change, where "motivation drives the cognition and metacognition needed for conceptual change" (p. 209). With intentional conceptual change, individuals have the goal of examining novel explanations and evaluating the need for knowledge reconstruction. Research is needed into to what degree the guided use of how explicit plausibility reappraisals facilitate both epistemic conceptual change and, in turn, the self-regulatory skills that promote conceptual change. This could help us better understand the interaction of learner and message characteristic deemed important by Dole and Sinatra's (1998) CRKM.

Greater understanding is also needed about how individuals personally define plausibility. In our empirical studies (see, e.g., Lombardi, Sinatra, et al., 2013), we asked participants to rate the plausibility of alternative explanations of a phenomenon with only a limited reflection on the nature of the plausibility judgments. Detailed interviews and think-aloud protocols could provide additional insight on how different people conceptualize plausibility.

## Supporting Scientific Thinking Through Plausibility Reappraisal

The PJCC also posits that plausibility judgments may be reappraised, and we call for more research on how instruction influences the development of scientific thinking and plausibility reappraisals. Previous research has shown that individuals can develop the ability to think scientifically at an early age (see, e.g., Metz, 2004), but the ability to

coordinate evidence and theory may not emerge until late adolescence and adulthood, if at all (D. Kuhn & Pearsall, 2000). However, instruction may promote critical evaluation and plausibility reappraisal in adolescents (Lombardi, Sinatra, et al., 2013), and research could examine if such abilities could be facilitated at an earlier age (e.g., upper elementary grades 3 to 5, when students may begin to understand some of the basic principles relating to the nature of science and scientific thinking; Metz, 2004). Whereas using the term *plausibility* with elementary students may prove to be difficult, elementary students may be able to learn how to weigh connections between evidences and theories and relate these connections to how scientists make judgments. It would also add to our understanding of basic cognitive processes to investigate how elementary students can coordinate multiple lines of evidence in making plausibility reappraisals, with the goal of increasing "students' understanding of science as a way of knowing" per the recently developed framework for K-12 science education (National Research Council, 2012, p. 251). More generally, development of metacognitive skills may influence the ability to reappraise plausibility judgments. Instruction that makes the plausibility judgment explicit may help facilitate evaluation of what an individual knows, along with increasing understanding about how they know. This metacognitive evaluation process has been shown to be particularly relevant to science learning (Schraw, Crippen, & Hartley, 2006). Studies examining development of scientific thinking, metacognition, and plausibility reappraisal may help us better understand how and when an instructional foundation for learning progressions on developing such epistemic practices can facilitate students' understanding about how individuals and scientists construct and reconstruct knowledge.

We propose that in additional to traditional experimental and quasi-experimental designs, researchers use a design-based research methodology to examine development of students' abilities to be critically evaluative and engage in plausibility reappraisal. Design-based research is based on the pioneering work of Brown (1993) and Collins (1992) and follows an iterative approach that seeks the simultaneous goals of "developing effective learning environments and using such environments as natural laboratories to study learning and teaching" (Sandoval & Bell, 2004, p. 200). Such studies are effective not only in gathering additional understanding into the cognitive processes that influence learning (including plausibility reappraisals) but also in developing instructional interventions that can be adapted and used by teachers.

The PJCC model points toward a diversity of information sources and instructional strategies that could lead to plausibility reappraisal. For example, Nussbaum and Edwards (2011) have shown that critical questions can be used to increase students' abilities to successfully evaluate arguments. Critical questions (e.g., "What is the likelihood?" and "Are there alternative explanations?") may enable students to engage in the type of critical evaluation that promotes plausibility reappraisal, although more research in this area is warranted. Furthermore, incorporating collaborative argumentation into instruction may allow for greater elaboration and evaluation when explicitly considering both judgments based on plausibilistic reasoning, as well as more precise probabilistic reasoning (E. M. Nussbaum, 2011).

Research of critical evaluation activities used in combination with various types of instructional text may also lead to increased understanding of plausibility reappraisal. A particularly effective medium for promoting conceptual change are refutation texts (Guzzetti, Snyder, Glass, & Gamas, 1993; Hynd, 2001; Sinatra & Broughton, 2011). Sinatra and Broughton (2011) wondered about "how best to increase the value-added benefit of refutation text for promoting science learning" and how the text "can be augmented to increase the refutation text advantage" (p. 389) to facilitate conceptual change. Research about incorporating critical evaluation and plausibility reappraisal into refutation text may be one way to increase this advantage. Other instructional strategies could be used with instructional text (or in a stand-alone mode) to support students to critically evaluate and facilitate plausibility reappraisal, such as knowledge of epistemic criteria and disciplinary norms (Duschl, 2008); knowledge of content and arguments on both sides of an issue (Kardash & Scholes, 1996); appreciation of the role of criticism (Szu & Osborne, 2012); and graphic organizers and other supports to help distinguish, coordinate, and evaluate explanations and evidence (Cavagnetto & Hand, 2012).

Educators may wish to stress the importance of reappraising plausibility judgments when students are faced with competing explanations to deepen understanding of both content and the process of scientific evaluation. Students should understand that scientific explanations—such as theories and hypotheses—are both tentative (Lederman, 1999) and subject to critical evaluation by the scientific community, where explanations "can be revised on the basis of seeing new evidence or of developing a new model that accounts for the existing evidence better than previous models did" (NRC, 2012, p. 251). Therefore, reappraising plausibility is a skill that may facilitate students' development of the ability to reason scientifically, especially around topics where a plausibility gap exists.

## CONCLUDING THOUGHTS

Our aim is to provide a theoretical model (the PJCC) for guiding future research and instructional practices that promote plausibility reappraisal and conceptual change, particularly when there is a gap in the plausibility between the scientific conception and individuals' background knowledge. The PJCC predicts that an appreciable gap

between plausibility of scientifically accurate conceptions and naïve background conceptions would result in little potential for conceptual change. But what topics specifically result in wide plausibility gaps? Controversial topics, such as climate change, stem cell research, genetically modified food, vaccinations, and biological evolution, could inherently have substantial plausibility gaps. But other, noncontroversial topics could also have a sizeable gap because personal experiences vastly differ from scientific ideas. For example, general relativity presents the idea that gravitation is caused by distortions in the combined dimensions of space and time (i.e., space-time) and gravitation is not really a force. However, individuals have great personal familiarity with the "force" of Earth's gravity as they observe falling objects and experience their own weight. The potential for changing their conceptions about gravitation may be severely limited by the plausibility gap between their existing force notion and the scientifically accurate space-time conception. We propose that greater understanding is needed about these types of topics that may have wide plausibility gaps (e.g., controversial, abstract) and the methods by which to reduce these gaps (i.e., through plausibility reappraisal).

Conceptual change is not simply matter of identifying and reconstructing misconceptions, especially when topics involve a potentially wide plausibility gap (e.g., controversial and/or abstract topics). Students should engage in considering alternatives that allow evaluation of alternative claims and the potential for plausibility reappraisal. Plausibility has long been acknowledged in conceptual change research but not articulated, and more thorough empirically testing of this potentially important mechanism is long overdue. The PJCC model attempts to begin a comprehensive and earnest scientific dialogue about plausibility judgments in conceptual change and epistemic conceptual change.

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