Section 4 Challenges and Solutions

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ASSESSING AND MODIFYING KNOWLEDGE

Facts vs. Constellations

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ABSTRACT

There is a rich philosophical and empirical history associated with examinations of the nature of knowledge. Epistemological queries have focused on determining how to characterize knowledge, and on developing methods of supporting people's accurate understandings. The resulting work has led to contentious debates about whether, when, and how knowledge is amenable to change. These are timely disputes given contemporary concerns about the consequences of exposure to inaccurate information from multiple perspectives (including but not limited to social media, fake news, and unsubstantiated reports), and how information from competing sources influences people's understandings of the world. Emerging investigations have focused on when and in what ways people might modify what they know. In the current chapter, we highlight two distinct ways that "what people know" has been characterized – as declarative ideas and as constellations of ideas. Different concepts and topics might reflect either of these representational possibilities, which has crucial implications for epistemological investigations and claims about how to modify knowledge. We highlight the challenges and problems that can emerge when researchers confabulate distinct conceptualizations of knowledge representation. These are important considerations for selecting methodological approaches, deriving theoretical models, and arguing for (or against) the generalizability of findings. Suggestions for wrestling with these issues are offered.

Key words: knowledge, epistemology, updating, learning, mental representation

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Classic and contemporary accounts of learning and comprehension are informed by philosophical and empirical examinations of knowledge, including ontological origins, development, and epistemology. This has also guided the design and implementation of instructional interventions in formal and informal learning settings. Fields including cognitive science, computer science, learning science, educational psychology, STEM content domains, literacy initiatives, history and civics education, curriculum design, special education, and philosophy have offered data, models, criticisms, and hypotheses about the way knowledge is constructed and how knowledge acquisition can be supported. In addition to many points of commonality, there are clear disciplinary differences across these fields with respect to how knowledge is studied, influencing the accounts proffered as speaking to the structure and contents of what people know (Hofer & Pintrich, 1997; Koedinger, Corbett, & Perfetti, 2012).

With respect to the nature of knowledge, two critical issues are regularly foregrounded by both academic and lay audiences given contemporary concerns about news reporting, media or authorial bias, information dissemination, and the spread of inaccurate information. The first involves determining how to characterize people's misunderstandings. The second involves identifying best practices for helping people reflect on and correct inaccurate understandings. These issues are the focus of this chapter, and are central to intellectual investigations of the nature and scope of knowledge. They reflect core topics within the theoretical philosophy of epistemology, namely, understanding what knowledge is and how it is constructed (e.g., Bonjour, 2002). Answering these fundamental questions proves relevant to concerns about people's exposure to, propagation of, and reliance on inaccurate information. They are also crucial considerations for discussing how people deal with information provided by multiple sources, as perspectives and presentations from both unreliable and reliable informants can include discrepancies, inconsistencies, and falsehoods (see Sanderson & Ecker, Chapter 26, for a discussion of "misinformation," and Kendeou et al., Chapter 27, for a discussion of "fake news"). Understanding when and why people notice and act on such issues requires clear explications of what knowledge is, including the processes and products involved in acquiring understandings and modifying what we know.

Addressing these issues involves identifying what is meant by terms including "misunderstandings" and "inaccurate understandings." A preliminary definition might identify an inaccurate understanding as running counter to what experts, evidence, and logic have determined to be valid. For example, someone who claims that the Earth is flat has failed to take into account an accumulated body of evidence to the contrary, and misunderstands the shape of the planet (and, as a result, other related issues). Not all misunderstandings, though, fit this easy definition. Many misunderstandings are associated with ideas and concepts for which there is substantial debate, including evidence for both sides of an argument, which makes assessments of accuracy less than trivial. For example, physics and metaphysical investigations of the nature of matter are sometimes presented as divided with respect to whether matter is composed of particles or strings. The two accounts involve sets of assumptions, sometimes overlapping and sometimes diverging, that make them difficult to reconcile. And yet specific elements of each account may be more or less viable under different circumstances depending on the evidence marshalled, the logical arguments provided, and the context of the particular physics problem being investigated.

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This highlights a general consideration for discussions of epistemology in a variety of content areas and knowledge domains, in no way restricted just to this physics example, and directly pertinent to inaccurate understandings. Namely, aspects of what people seem to understand might be correct or incorrect depending on the time, context, and method by which knowledge is invoked. Misunderstandings therefore are a function of agreed upon principles and evidence, at times dependent upon situational considerations (Halldén, Scheja, & Haglund, 2008; Vosniadou & Brewer, 1992). While some misunderstandings are circumscribed, such as being wrong about particular facts (e.g., that the Atlantic is the biggest ocean in the world when in fact the Pacific is the largest), other misunderstandings can involve a variety of components that are difficult to disentangle, and that can motivate additional inferences and ideas that speak to other conceptual topics and issues (e.g., misconstrued accounts of complex phenomena such as the causes of economic crises or the repercussions of legislation on society).

But what precisely constitutes the knowledge inherent in people's misunderstandings? This question necessitates identifying the fundamental architecture of knowledge, which means the form and structure of what people know. If knowledge is, for example, rigidly held, with ideas encoded as fully fleshed out accounts and theories, our expectations about the best methods for addressing potential misunderstandings, and how easy they will be to address, will be quite different than if knowledge is more malleable, with concepts variably invoked as a function of experience, credibility, available evidence, context, and so on. These possibilities are actually the skeletal versions of two sides of rigorous debate between researchers in the cognitive and learning sciences (diSessa, 2008; Özdemir & Clark, 2007; Smith, diSessa, & Roschelle, 1993).

Specifying the nature of knowledge and misunderstandings is therefore a more challenging issue than might be addressed in a single chapter or volume. Nevertheless, we begin (some might say revisit) this issue with a discussion of two general ways that knowledge has been characterized to help outline what "inaccurate understandings" are or might be. This discussion is necessary for addressing the earlier identified issues – determining how to characterize people's knowledge, and using that information to help people build and maintain more accurate understandings. These concerns necessarily move beyond purely philosophical questions about the nature of knowledge, motivating applied considerations relevant for developing effective assessments, curricula, and instructional supports.

CONTEMPORARY ACCOUNTS OF KNOWLEDGE

Theorists and researchers have characterized knowledge in a variety of ways, which has led to vociferous theoretical debates. Differing opinions about those characterizations, as informed by empirical examinations, has resulted in opposing orientations and frameworks not just with respect to emerging epistemological accounts, but also for derived recommendations about the design of instructional materials and environments. It is beyond the scope of this chapter to describe all of the various accounts and empirical projects supporting these views. Rather, in defining accounts and implications related to the nature of knowledge, we will draw heavily on literature from domains dedicated to studying the modification of knowledge, as this is the primary focus of this chapter. In doing so, we will separate prevailing accounts into two

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groupings, fully realizing that such a dichotomous organization eliminates nuances associated with the accounts. However, this organization captures critical elements of the character of such accounts, and allows for highlighting critical considerations and limitations of their underlying arguments. (More generally, these disparate views connect with the theme of this volume, highlighting the differing perspectives that routinely emerge in people's investigations and arguments concerning the nature of knowledge.)

One set of views focuses on knowledge as complete, organized contents stored in memory. These "packets" of knowledge are well-formed, being encoded, stored, and retrieved wholesale from memory. Accounts endorsing this perspective are often termed theory or holistic views (e.g., Caramazza, McCloskey, & Green, 1981; Carey, 1985; Chi, 2005; McCloskey, 1983; Vosniadou, 1994). A crucial component of these accounts is that knowledge is stored in coherent, organized groupings involving relatively stable components. Thus, knowledge may be consistent over time, particularly in the absence of any substantial intervention aimed at encouraging the encoding or construction of new understandings. In practice, such views of knowledge often highlight declarative facts and schematic understandings as being applied during comprehension. Because these representations are holistic, any attempt at modifying them requires adopting a new schema or idea that is more viable or accurate than a previous one. Rather than attempting to shift or mold singular ideas in a direction more in line with expert understandings, for example, holistic views of knowledge may suggest that learners need to rely upon entirely new understandings instead of their pre-existing knowledge structures (McCloskey, 1983; Posner, Strike, Hewson, & Gertzog, 1982). As a result, inaccurate understandings obstruct the development of more rigorous understandings.

Another set of views has been positioned in opposition to these holistic accounts contending that when people encode, store, or retrieve information from memory, no set or organized system or even predictable structure is involved. Rather, disparate pieces of knowledge may be recruited, depending on individual and situational variables associated with an encoding or retrieval context (Clark, 2006; Saglam, Karaaslan, & Ayas, 2010; Smith et al., 1993). This view contends that during comprehension, people draw upon a range of different "bits" of knowledge and attempt to establish coherence among them, with the particular bits a learner utilizes varying across time and setting. Accounts endorsing this perspective have been termed *knowledge*in-pieces or fragmented views (e.g., diSessa, 1993; diSessa, Gillespie, & Esterly, 2004; Smith et al., 1993). By these accounts, when individuals acquire information, newly constructed representations are of course potentially stored in long-term memory, but those representations are not guaranteed to be accessed routinely or consistently later on. This creates distinct challenges for learning, requiring more than simply updating or replacing coherent, consistently retrieved knowledge structures. Because the ideas underlying knowledge are less than systematic, coherent, or holistic, and are instead informed by many different experiences and contexts, attempts to completely modify what someone may understand can be difficult and unlikely to succeed. Even if modification is successful, as demonstrated with the acquisition of a more valid understanding, it need not guarantee the same valid understanding will routinely emerge in the future because of the interaction of factors described above. Conceptualizing knowledge as fragmented can allow for fine-grained examinations of the knowledge that learners possess, as it requires attending to and characterizing

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individual aspects of knowledge on its own terms. One argument is that such attention affords more precisely targeted interventions for fostering the development of rigorous understandings by leveraging elements of inaccurate understandings that may be useful in different circumstances.

Again, our characterizations here simplify the varied conceptualizations of knowledge that have been offered by theorists and researchers across fields. Nevertheless, this dichotomization helps elucidate two well-established perspectives that more nuanced accounts often endorse to a greater or lesser extent. Some views have even attempted to integrate holistic and knowledge-in-pieces views in efforts to describe human epistemology and explain how knowledge develops over time (e.g., Alexander & Baggetta, 2014; Hammer & Elby, 2002). To illustrate, consider an important contrast between expert and novice representations of knowledge: Experts, as compared to novices, often hold not just a greater quantity of knowledge, but also demonstrate more effective use of that knowledge to solve problems. Experts can flexibly draw upon a range of different concepts and relational connections during problem solving in their domain of expertise (Chi, Glaser, & Rees, 1982). Novices, who have considerably less experience to draw upon, may not process incoming information as effectively, or readily recognize meaningful patterns (Chase & Simon, 1973). For example, while experts place problems into groups based on the underlying semantic similarities core to the problems, novices organize problems based on potentially irrelevant surface features and descriptors (Chi, Feltovich, & Glaser, 1981; Novick, 1988). Novice knowledge may therefore reflect more disparate, piecemeal organizations that include varied features related or unrelated to underlying core concepts in a domain. With continued experience and practice, their representations may become more theory-based, allowing for easier identification and classification of the crucial elements and relational connections that characterize problems. We have described this integrated possibility not necessarily as an endorsement of its validity, but to illustrate how accounts have been leveraged in theoretically intriguing (and not uncontroversial) ways that attempt to bridge holistic and piecemeal views.

MODIFYING FACTS VS. CONSTELLATIONS OF KNOWLEDGE

The perspectives articulated above have, as critical to their accounts, provided explicit notions of how easy or challenging it might be to modify knowledge. We have opted to use the relatively generic term *modify* when referring to any attempt to alter what people know as it could involve a variety of processes and activities, including but not limited to assimilation (i.e., adding to what is already known), accommodation or revision (i.e., changing what is known), compartmentalization (i.e., tagging some portion of knowledge as relevant under some circumstances or situations but not others), conceptual change (i.e., impacting networks of interconnected ideas that are part of larger conceptual structures), and restructuration (i.e., building new representations and ways of thinking). (We will later focus on some of these cases to highlight specific kinds of investigations with respect to modifying knowledge.) The term updating is also popular, although it might be taken to mean that previous information is no longer available, despite a considerable body of evidence indicating that not to be the case even with projects that explicitly use the term (e.g., O'Brien, Rizzella, Albrecht, & Halleran, 1998; Taylor & Rapp, 2006).

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Our decision to rely on the term modify relates not just to the range of effects that may or may not occur during learning experiences, but also aligns with the line of argument we will attempt to put forward: The ways in which researchers and theorists conceptualize knowledge, and whether and how modification might occur, is linked to their methodological decisions and any derived empirical claims being offered. These issues could be discussed in a variety of ways. We focus on how prevailing accounts conceptualize people's inaccurate understandings, as these constitute situations in which it would be preferable for people to modify what they know. This necessitates explicating what is constrained by the nature of knowledge articulated in the accounts, and also what might be expected or likely to obtain following attempts to modify knowledge, as based on empirical findings.

We begin by considering how *holistic* accounts of knowledge tend to conceptualize inaccurate understandings. Recall that these accounts hypothesize that knowledge is typically stored in coherent structures, which may be correct or incorrect. The goal is to attempt to modify incorrect accounts with valid and accurate understandings. As an example, consider someone possessing an incorrect declarative idea, such as where a country is located (e.g., Mexico being part of South America rather than North America), or the timeframe of a particular historical event (e.g., that the French and Indian War occurred in the 1800s rather than 1700s). If a factual misunderstanding can be modified to reflect accurate understandings, the resulting changes in learner knowledge could be classified as knowledge revision, with the previous inaccuracies replaced by new knowledge. To clarify this point, imagine a learner who has a factual misunderstanding that the capital of Illinois is Chicago. The goal of instruction would be to revise that incorrect understanding with the correct fact. Negating the idea that Chicago is the capital and offering the correct idea that Springfield is the capital can thus be helpful. Additional activities can strengthen and maintain this new understanding in memory, such as including repeated exposures to the accurate idea, asking learners to generate the idea rather than simply reading it (Jacoby, 1978; Roediger & Karpicke, 2006), and offering supplemental explanations (e.g., that state capitals are not necessarily, or even all that often, located in the most populous cities within a state). These activities help learners correct misunderstandings and maintain more coherent, valid knowledge (e.g., Rapp & Kendeou, 2007).

Of course, not all knowledge can be appropriately categorized as involving declarative facts, and may thus be less likely to enjoy benefits from these modestly designed instructional activities. But many kinds of misunderstandings *do* involve unitary, stable ideas that have been encoded based on evidence or claims. These declarative misunderstandings should not be characterized as unimportant to people's everyday considerations as they often underlie and inform deeper and more elaborate understandings. For example, identifying the locations of US state capitals could support inferences about historical events, economic developments, and other socio-historical conjectures and hypotheses. A focus on declarative misunderstandings allows for envisioning some knowledge structures as amenable to relatively simple and direct prompts for modification.

The requisite processes underlying such modification have been articulated in a variety of models, such as the Knowledge Revision Components (KReC) Framework (Kendeou & O'Brien, 2014). There are several stipulations associated with the

framework, but we focus on three critical to the discussion here. When learners are presented with information running counter to what they know, they first engage in *co-activation*. This requires simultaneously considering newly presented information and relevant prior knowledge. The new information must then be *integrated* with prior knowledge to allow for modifying existing understandings and to connect new and old information in memory. The remaining challenge is that learners need to *activate* their new understandings, perhaps as prompted by instructions or other external motivators, to a greater degree than their prior incorrect knowledge. If multiple sets of competing, co-activated ideas are equally available, people may be confused and/or default to what they had learned previously (Rapp & Salovich, 2018). Revision, in this framework, necessitates the encoding of new ideas in mental structures, with learners privileging those new ideas over previous structures if sufficient attention, evidence, and practice are applied to those newly encoded memories. A critical assumption of this model, and others including the Landscape model (van Den Broek, Rapp, & Kendeou, 2005), the Discrepancy-Induced Sources Comprehension Model (Braasch & Bråten, 2017), and the RI-Val model (O'Brien & Cook, 2016), is that revision does not result in prior understandings being completely overwritten or eliminated. Rather, new structures receive more support and activation that afford their use. Any resulting understandings might therefore be classified as successful knowledge revision. The term *reliance* rather than revision is sometime invoked to refer to people's use of a particular set of ideas or understandings over others (Donovan, Theodosis, & Rapp, 2018; Rapp, Hinze, Kohlhepp, & Ryskin, 2014; Rapp & Salovich, 2018).

A variety of methods for encouraging reliance on more appropriate and valid ideas have been proposed. Empirically validated methods often involve the use of materials that confront people' misunderstandings by highlighting discrepancies between what they know or believe and what they *should* know or believe (Braasch & Bråten, 2017; Braasch, Rouet, Vibert, & Britt, 2012). An example involves refutation texts, which are written materials that point out prominent misunderstandings, discount their utility and validity, and provide accurate accounts intended to counter the misunderstandings (Hynd & Alvermann, 1986; Sinatra & Broughton, 2011; Tippett, 2010). Refutation texts support updating by facilitating the processes that underlie knowledge revision as articulated above. They present information such that inaccurate and accurate structures are potentially co-activated, present the accounts in close proximity with explicit descriptions intended to integrate them, and include explanations highlighting one co-activated idea as more reasonable or more accurate than the other, increasing the likelihood that the highlighted idea will be available and activated during subsequent opportunities to apply knowledge (Kendeou & O'Brien, 2014).

A large body of literature has consistently shown that refutation texts support the development of accurate understandings, with readers more likely to remember, endorse, and use accurate as compared to inaccurate information after reading refutation texts relative to texts that simply present ideas (e.g., Guzzetti, Snyder, Glass, & Gamas, 1993; Hynd & Alvermann, 1986; Sinatra & Broughton, 2011; Tippett, 2010). Readers exhibit more frequent efforts to integrate text content with prior knowledge after reading refutation texts as compared to after reading non-refutation texts, as measured with verbal productions during reading (Kendeou & van Den Broek, 2007). Readers also remember more content generally, and more accurate content specifically,

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after reading refutation compared to non-refutation texts as measured with free recall tasks (Donovan, Zhan, & Rapp, 2018). They also show enhanced performance on a variety of comprehension measures (e.g., recall and recognition tests for text content) after reading refutations relative to non-refutation texts, with the resulting memory benefits retained over time (Frède, 2008; Nussbaum, Cordova, & Rehmat, 2017).

Much of what we know, however, exhibits greater complexity than should be associated with separable, declarative facts. As examples, understandings of the role of vaccinations in maintaining public health, the antecedents and consequences of military conflicts, or even the causes of climate change (see Lombardi, Danielson, & Young, 2016 for a discussion of climate-related considerations), cannot be easily broken down into disparate facts amenable to simple correction. Instead, they interact with contextual factors as well as with people's existing knowledge, beliefs, and identities. This is not meant to diminish the importance of factual accuracy, but rather to indicate that many ideas and concepts are complicated, necessitating different considerations for theoretical accounts and remediations. If these understandings involve many interacting elements, holistic approaches are unlikely to encourage modification. When the representations underlying someone's perceptions and understandings of the world invoke multiple moving parts that are differentially active and appropriate under different circumstances, and that lack a clear and easily constructed set of explanations, these complex knowledge structures are more likely associated with a knowledge-inpieces rather than a holistic view. When understandings involve a network of related ideas, each of which might fall along a continuum of accuracy, with the connections between them also conveying more or less accuracy, it is less likely that a targeted intervention designed to dispute a particular element from a holistic perspective would be particularly effective.

This is worth deep consideration given the range of perspectives that are often associated with various complicated topics, and for which we might hope to encourage modifications to support evaluative and accurate understandings. Consider claims about vaccinations as an example. Different forms of knowledge could be drawn upon in attempts to explain the impact that vaccinations have on public health (Zingg & Siegrist, 2012). People's understandings of scientific findings regarding the efficacy of vaccinations for reducing or eradicating diseases, their conceptualizations of the hallmarks of rigorous scientific inquiry, and their exposure to pertinent concepts like "herd immunity," could all be critically implicated. Social constructions about the roles of doctors, schools, pharmaceutical companies, and other actors in proposals for and against vaccinations may likewise come into play. Further, direct interactions with disease outbreaks, health sciences, and healthcare service providers, among numerous other possibilities, however idiosyncratic, also influence people's understandings of vaccines. A plethora of personal experiences and information obtained through primary and secondary sources of differing credibility and with differing presentation goals can make understanding complex concepts and models (such as inoculation) difficult (see Moran, Lucas, Everhart, Morgan, & Prickett, 2016). Even experts who regularly convey accurate ideas can hold pieces of incorrect understanding, although they are better than non-experts at suppressing reliance on those inaccuracies (Kelemen, Rottman, & Seston, 2013; Masson, Potvin, Riopel, & Brault-Foisy, 2014). Thus, the sets of experiences and information people activate,

defer to, or discount as they debate and make decisions about vaccinations is influenced by the situations and contingencies in which they are having those debates and making those decisions.

Delineating an exhaustive list of the kinds of knowledge of potential importance to the topic of vaccinations, or to any other topic or account, would be impossible. Examples such as this one are therefore intended to illustrate that different kinds of interventions may be necessary for different misunderstandings, given the potential diversity in their constituent components. Interventions intended to encourage reliance on a particular correct piece of information may have limited utility when the underlying misunderstandings incorporate many and variable pieces of knowledge. When knowledge involves constellations of different ideas coalescing into momentby-moment understandings that need not remain consistent or coherent over time, *conceptual change* may be necessary rather than the previously discussed revision approaches. We discuss this next as it requires (and exemplifies) a specifically knowledge-in-pieces approach to modifying knowledge.

Conceptual change involves modifications to central or core aspects of particular understandings in a network of knowledge (made up of encoded facts, percepts, interpretations, and so on), and is considered an especially challenging and time-consuming form of learning (diSessa & Sherin, 1998; Gentner et al., 1997). Unfortunately, the term conceptual change has at times been applied to *any* attempt to modify knowledge, whether involving a single fact or a complicated network of ideas. Distinguishing conceptual change from the modification of singular ideas is integral for developing precise accounts of knowledge change and suitable interventions to induce it (Kendeou, Butterfuss, Van Boekel, & O'Brien, 2017). We endorse the view that, in contrast to knowledge revision, conceptual change necessitates modification of elements of knowledge networks and constellations (which again are no more or less important than other types or forms of knowledge), and is a gradual, effortful process (diSessa & Sherin, 1998; Smith et al., 1993).

To differentiate the ways conceptual change gets liberally used and the specific instances to which it should refer, consider some concrete examples. When a student encodes a new idea into their existing body of factual knowledge about vaccines (e.g., that Edward Jenner pioneered the development of the smallpox vaccine), conceptual change would not be the most appropriate explanation for such learning. This example involves encoding a single idea or fact that does not necessitate reorganizing or restructuring knowledge networks. Similarly, some kinds of inaccurate ideas (e.g., misunderstanding vaccines to be a contemporary invention rather than dating back to the 18th century) can be discounted and revised by providing a single case or example of why that idea is incorrect. In stark contrast, if someone held the conviction that the choice of whether to vaccinate is an independent, free decision with no ramifications for society, a brief refutation would be insufficient for addressing this idea, given it is likely informed by many other related understandings (or misunderstandings) about public health, disease spread and prevalence, the development and implementation of vaccinations, and so on. Any effort to modify this misunderstanding would require addressing the multiple, interrelated ideas and concepts associated with it. Conceptual change, as exemplified here, requires more than a single contradictory example or even extended refutation, given that changing one element of a constellation has no

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guarantee of enacting cascading effects on related knowledge components. Activities associated with conceptual change require multiple experiences and approaches to redress constellations of knowledge (diSessa & Sherin, 1998). When our understandings are buffeted and informed by diverse perspectives involving different values, beliefs, forms of evidence (or views on what counts as evidence), logical claims, flawed arguments, perceptual experiences, and so on, repeated exposures to accurate information offered through potentially different modalities proves crucial for supporting conceptual change.

By this view, whether misunderstandings are constrained and bounded or made up of many interacting representations, traditional teaching methods involving direct instruction and attempts to correct inaccuracies are often insufficient for promoting accurate understandings (Chi, 2008; Simpson & Marek, 1988). They can fail to identify or address ideas in students' knowledge, or the ways those ideas are organized and related in memory, that are implicated in the misunderstanding. Communicating accurate ideas without careful assessment of learners' pre-existing knowledge about a topic may not lead to substantive changes in the quality of learners' complex misunderstandings. And if only some aspects of a complex misunderstanding are addressed, or if the accurate explanations offered map poorly onto a learner's prior knowledge, misunderstandings are likely to remain (Chi, 2005; Fisher, 2004).

Conceptual change therefore repositions the design of instructional experiences from the direct teaching of accurate ideas to the deep consideration of a student's existing knowledge on a given topic, and the value that knowledge may hold for the development of more rigorous understandings (diSessa & Minstrell, 1998; Swanson & Collins, 2018). Rather than simply presenting correct ideas about vaccinations in a public health class, an instructor might instead frame the learning experience as a discussion about vaccinations to which students would contribute their current understandings of the topic. This activity can then provide the foundation for more nuanced understandings to be developed through scaffolded tasks and discourse (Lombardi, Bailey, Bickel, & Burrell, 2018). What makes this approach valuable is that it emphasizes the utility of a learner's existing knowledge. By drawing on and highlighting pieces of knowledge that learners possess about a topic, rather than focusing on the flaws or inaccuracies in those understandings, instructors can "take stock" of learners' knowledge, both formatively and summatively, during remediation. Such an approach is not easy, not without potential drawbacks, and not appropriate for all learning environments or topics. But a focus on sharing and building upon existing knowledge may be useful in attempts to develop more sophisticated understandings of topics involving constellations of knowledge. Some approaches that explicitly endorse this perspective, albeit with variability in the particular learning goals of interest, have included constructivist and constructionist learning environments (e.g., Wilensky & Reisman, 2006; Wilensky & Resnick, 1999), problem-based learning tasks (e.g., Hmelo-Silver, 2004), and analogical reasoning activities (e.g., Brown & Clement, 1989; Chi, Roscoe, Slotta, Roy, & Chase, 2012). It is worth noting that these approaches highlight the need for addressing misunderstandings by exposing learners to ideas from multiple perspectives and using multiple representations, with careful design to ensure the accompanying presentations provide consistent evidence for valid ideas and inferences.

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CHALLENGES FOR ADDRESSING INACCURATE UNDERSTANDINGS

Following from the discussion above, knowledge revision should be specific to modifying people's use of particular declarative facts and ideas, while conceptual change should reference attempts to address multiple critical elements of ideas in a shifting knowledge space. When considered this way, many contemporary empirical investigations and theoretical discussions seem to confound processes of knowledge revision and conceptual change. This happens in at least two ways. First, it occurs when researchers hypothesize about or argue that their attempts at addressing inaccurate declarative ideas demonstrate broader modifications to knowledge. For example, people's misidentification of Chicago as the capital of Illinois likely involves a declarative misunderstanding rather than some larger set of ideas coalescing into the inaccurate notion. Categorizing this example as an instance of conceptual change overstates the degree of modification that is required, and the modification that results after an accurate version of the fact has been provided to correct the misunderstanding.

Second, projects can inappropriately describe complicated, piecemeal knowledge organizations as having been successfully modified following some modest attempt at remediation. In these cases, the problematic account might focus on how a rich understanding of some STEM topic has been instantiated by addressing a specific fact or idea. For example, an attempt to address people's misunderstandings about vaccinations might apply a specific game-like activity to indicate how a lack of vaccinations can lead to disease outbreaks. This tack, while useful, only addresses one element worth considering with respect to understanding vaccinations. As previously discussed, people's understandings of vaccinations, and many other topics, are likely to implicate a wide and idiosyncratic range of understandings. Focusing specifically on one element of the topic, such as disease propagation for vaccinations, addresses only a subset of the knowledge required to elicit a desired change.

In some cases, addressing a particularly important component of knowledge can have crucial utility, perhaps leading to cascading modifications of related knowledge structures as foundational elements are reconsidered and knowledge undergoes restructuration (Chi, 2008). But the effectiveness of such a targeted attempt to modify knowledge is dependent upon the sophistication and rigor with which researchers have ascertained the particular knowledge structures in question (including but not limited to how central the issues to be redressed are, and whether they are malleable on their own or not). In lieu of such an analysis, it is possible that individuals involved in the intended modification activity might reconsider one element of the situation or issue, but nevertheless endorse alternative explanations that still allow for understanding vaccinations as problematic even in the face of, or perhaps despite, the dangers of disease propagation.

To summarize: Given that inaccurate understandings can exhibit notably different characteristics, it is crucial to utilize appropriate terms and their underlying propositions in projects attempting to address them. If an approach designed to promote revision of factual misunderstandings is implemented to address constellations of inaccurate ideas, some components underlying the inaccurate understandings may receive insufficient attention or be overlooked. The desired conceptual change may therefore not be attained. Similarly, conceptual change activities might not be

necessary to effectively revise specific declarative understandings, and might even encourage new, incorrect understandings if applied inappropriately.

An important, related concern is that researchers often utilize different methods to describe and address people's misunderstandings. Diverse approaches and perspectives, in principle, are fine and probably preferred, as different methods can offer useful epistemological insights or inform practical guidelines for instruction. But a challenge is that the particular method used to measure or address people's understandings might bias expectations for the kinds of knowledge issues attended to, as well as influence the approach selected to address any misunderstandings. Consider, for example, if a researcher uses intensive prompt-driven, semi-clinical interviews to elicit discussions of issues related to a concept, such as understandings of vaccinations. Such clinical interview methods are common in assessing knowledge modification (Posner & Gertzog, 1982), and can promote responses that appear to reflect piecemeal knowledge as a function of the methodology. This is because the conversational and open-ended nature of interviews affords speakers the chance to contribute more moment-by-moment productions, which can result in understandings often appearing more disjointed and varied than those elicited by other methodologies (Sherin, Krakowski, & Lee, 2012; VanSledright & Brophy, 1992; Vosniadou & Brewer, 1992). As a contrasting example, when people are asked to judge the validity of single sentences, the obtained results do not provide nuanced insight into the nature of the underlying knowledge structures being retrieved (or not) to make those decisions. Characterizing knowledge as declarative in this latter case is unsurprising, as the methodological tool here constitutes declarative statements, limiting or disallowing consideration of more spontaneous and elaborative productions (Posner & Gertzog, 1982). In a more extreme case, the method chosen to assess knowledge can even fail to detect existing misunderstandings. Consider that when children are asked to report the shape of the Earth, many correctly identify it as round. However, when instructed to provide a visual representation of their understandings, some draw erroneous shapes (such as flat pancakes) and, when asked to describe their understandings via interviews, may admit to thinking that people could fall off the surface of the Earth (Vosniadou & Brewer, 1992). Focusing on one method can only provide partial insight, or even prove invalid, for identifying what people know.

As an additional challenge, the particular method selected, and how it might be applied, can be informed by *a priori* expectations about the ways in which knowledge is structured or organized. This establishes obvious concerns about researchers finding evidence for claims or accounts they hope to find evidence for, rather than allowing for a grounded approach to observing trends and patterns in data. It also incites worries that a method might be utilized because it is associated with a particular methodological expertise or theoretical investment at the exclusion, intended or not, of other valuable approaches. This is not to devalue any particular methodology in promoting or assessing the learning or modification of knowledge. Both holistic retrieval and open-ended discourse can promote learning (or relearning) of information (Murphy, Wilkinson, Soter, Hennessey, & Alexander, 2009; Roediger & Karpicke, 2006). Rather, the upshot is that the methods researchers use to assess inaccurate understandings are necessarily motivated by, and consequently motivate how, knowledge will be examined and described (Bryce & Blown, 2016). Projects

that collect open-ended responses from large bodies of conversational data, and/or that afford moment-by-moment insights into productions often offer more elaborative, nuanced, and piecemeal indicators of understanding than do projects that allow premeditated responses and/or that restrict the range of responses or decisions an individual can provide on a task (Posner & Gertzog, 1982; Sherin et al., 2012). These differences should be both acknowledged and appreciated by researchers and theorists collecting and reviewing the data.

Again, this is not meant to suggest that projects involving interviews or statement judgments are always problematic, or that one is always preferred over the other. Rather, our assertion is that researchers should be aware of and up front about how their selected dependent measures and research tasks embody potential predispositions as to how knowledge will be conceptualized and characterized. (See Rapp & Mensink, 2011, for a similar discussion more generally related to methodological decisions.)

NEW INSIGHTS AND FUTURE DIRECTIONS

Different characterizations of knowledge inform the ways in which scholars attempt to measure and discuss misunderstandings, and the accompanying interventions highlighted as most fruitful for addressing them. This necessitates careful consideration of whether the specific misunderstandings of interest involve singular declarative ideas or constellations of ideas. Empirical examinations could usefully document the consequences of an inappropriate match between the nature of a misunderstanding and the method used for its correction, as well as when context, credibility, prior learning, and other interacting factors are promoted or neglected in attempts at intervention. Consider that incomplete or mismatched attempts could relate to so-called backfire effects, in which projects that intend to target specific interventions, rather than having hypothesized beneficial effects, actually result in greater investment in inaccurate ideas as well as rejection of correct propositions (Nyhan & Reifler, 2010).

Fruitful examinations must also recognize and attend to the challenges associated with assessing knowledge. Any misunderstandings being assessed (e.g., the risks of vaccines, how governments operate, the impact of immigration on the economy) may or may not reflect actual or emerging constellations of ideas, and researcher intuitions about whether misunderstandings are declarative or not are insufficient for cataloging the nature of people's knowledge. Moreover, in efforts to categorize misunderstandings, we must acknowledge that the methods underlying assessments influence the emerging characterizations of knowledge, and associated expectations as to the appropriateness of particular intervention approaches. We call for careful consideration of the constraints and limits of methods used to address epistemological questions, and deep contemplation as to where, when, how, and from whom any expected norms of understandings are derived.

The question, then, is how to be more mindful in the assessment and modification of people's understandings. Projects that attempt to apply multiple methods, assessing both moment-by-moment thinking and the resulting products of such activity, should prove useful for informing epistemological accounts and instructional designs. Other approaches and strategies can effectively supplement multi-method projects. For example, the development and application of effective assessments would benefit

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from collaborations with experts in various content domains (e.g., STEM content areas). Expert insight into how knowledge is constructed and organized in a given topic area can inform decisions as to what would constitute evidence of accurate understandings and modified knowledge. This relates to a more general concern that studies purporting to examine such issues often fail to apply appropriate pre-test or pre-intervention assessments, calling into question whether learning is actually being tested as part of the project. Whether projects attempt to describe the preconceptions people possess using microgenetic analyses of interview responses, or develop experimental investigations to highlight the utility of refutation texts, some account of what people knew prior to participating in those procedures proves crucial for characterizing the contents of knowledge and the consequences of modification activities.

Although modifying inaccurate understandings may be difficult, attempts to do so are not fruitless. Many of the intuitive ideas that people have about the world are modified through formal and informal educational experiences, and maintained over time (e.g., Chi, 2008). Contemporary accounts should benefit from attending to methods that have successfully yielded substantial, durable change in people's understandings in content domains. This should also involve consideration as to whether and how these beneficial experiences might be applied to a broader range of topics. Efforts to surface the root(s) of a misunderstanding through deliberate assessment, including consideration of the complex individual and contextual factors that play a role in people's understandings, proves crucial for developing theoretical accounts and applied interventions that support people's thinking.

Future work also needs to consider the varied inputs that feed into people's experiences with the world, which can inform accurate and inaccurate understandings. Some accounts have highlighted the perceptual experiences that underlie understandings of STEM topics (e.g., Andre & Ding, 1991; diSessa, 1993), while others have explicated how carefully designed textual presentations can address STEM misunderstandings (Hynd, Alvermann, & Qian, 1997; Kendeou & van Den Broek, 2007; Sungur, Tekkaya, & Geban, 2001). These accounts focus on particular subsets of presentations as provided through grounded systems or through symbol systems. And yet our understandings about the world are informed by a diverse array of presentations, ranging from direct interactions with physical objects, to indirect information claimed and conjectured by others, to abstracted accountings derived across multiple experiences. Wrestling with the challenge of both how to account for these diverse experiences, as well as how to effectively examine them using qualitative and quantitative methodologies, is important for the field going forward. Identifying which sources people rely on and why proves necessary for establishing accounts of when and how people acquire and modify knowledge. In addition, contemporary concerns about the validity of what we routinely encounter from news outlets, social media sites, word-of-mouth, and so forth, call into question how we reconcile information presented from sources that may or may not be invested in presenting the truth. Future work should interrogate how people experience complex information environments, and the consequences of those experiences for knowledge acquisition and application during everyday problem solving and decision making. This requires establishing rich theoretical accounts that inform applied considerations with respect to describing and supporting people's learning from and about the world.

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CONCLUSIONS

Researchers often laud different instructional approaches for helping people develop sophisticated understandings, including but not limited to refutation-based experiences, direct challenges to pertinent claims, hands-on construction activities, and traditional lectures. The approaches that might be most successful for promoting useful understandings crucially depend upon what people already know as well as the nature of the knowledge that underlies their comprehension. Greater care and clarity must be applied in articulating these features at the outset of instructional design, such that an intended approach aligns with the characteristics of the knowledge in question. We reiterate that research and application is necessary for effectively modifying both people's declarative understandings as well as their integrated knowledge structures. In many cases, our conceptual understandings are derived from declarative facts, in addition to many of our declarative claims being based on complicated accumulations of disparate ideas and experiences. Instructional approaches are required to help people develop correct understandings of the capital of Illinois and what roles vaccinations play in maintaining public health, although the methods most suitable for targeting misunderstandings across these kinds of topics may and most likely need to differ.

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