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Establishing Generalizable Mechanisms

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Introduction

Humans did not evolve to make the work of experimental psychologists easy. Relative to the other sciences, psychological science must employ many more tools to assess and control variability. The natural phenomena we attempt to explain are not only associated with genetic variation, but with genetic expression that is contextually determined (epigenetics). Substantial differences in experience create further variability, arising through culture, the environment, and developmental history. During immediate cognitive and affective processing, contextual factors not only have continual influence, their effects are often substantial. Furthermore, every act of processing changes the structure of the brain via neural plasticity, such that responses to the same stimulus are never the same (e.g., the ubiquitous phenomenon of repetition priming). As a consequence of all this variability, different individuals typically perform a task differently, and the same individual performs it differently across occasions. Even on the same occasion, a given individual's performance tends to vary considerably from trial to trial. At each moment, widely varying influences at multiple time scales combine to produce a single instance of cognition, affect, and behavior. And then there is the issue that human consciousness affects the phenomena we attempt to explain via demand, social desirability, intuitive theories, mind wandering, and so forth.

Given these challenges, it is not surprising that experimental psychologists often tend to look where the light is good. Rather than trying to deal with all relevant sources of variability, we often do everything we can to avoid these complexities and keep them under control, especially given how much we value demonstrations of causality. The result is idealized laboratory paradigms that somewhat resemble what happens in the real world, but that are often only distantly related to the real-world phenomena of ultimate interest. Indeed, if one wanted to be uncharitable, experimental psychologists often do not really care much about actually explaining real-world phenomena—instead they have much more enthusiasm for understanding laboratory phenomena as ends in themselves. After all, if an elegant formal model is only possible with an idealized paradigm, why should we concern ourselves with studying messier natural phenomena that prevent us from demonstrating our elegant methodological and modeling skills?

In their target article, Miller et al. (this issue) not only appreciate the dilemma that experimental psychologists face, they respect both sides of the issue, and offer provocative suggestions for resolving it. On the one hand, Miller et al. value the importance of isolating cognitive, affective, and biological mechanisms, and understanding their roles in intelligence and behavior. On the other, Miller et al. are rightly concerned that mechanisms established in idealized laboratory paradigms often do not generalize to real-world contexts (as supported by various lines of evidence they cite, including Brewer & Crano, 2014; Cronbach, 1957; Henrich, Heine, & Norenzayan, 2010; Shadish, Cook, & Campbell, 2002). Rather than being satisfied with the elegance of performing good laboratory research, Miller et al. instead ask researchers to establish mechanisms that operate in the real-world, and that have implications for important social issues.

Increasing numbers of psychological scientists have similar aspirations. As Miller et al. (this issue) note, psychological science will not garner the same attention, respect, and funding as physics, chemistry, and biology until—like these other sciences—it brings its methodological apparatus to bear effectively and compellingly on important real-world issues. Continuing to focus on idealized laboratory paradigms that do not explain real-world phenomena will keep psychological science not only from achieving its promise, but from producing practical and important social benefits that are sorely needed.

Miller et al. (this issue) champion a powerful approach for rigorously establishing causal mechanisms likely to operate in the real-world—Systematic Representative Design (SRD). While keeping much of the critical experimental apparatus that makes it possible to isolate and understand cognitive mechanisms (e.g., manipulation, randomization), Miller et al. further suggest new approaches for assessing these mechanisms in real-world contexts. Not only do Miller et al. make concrete suggestions for how to establish the content of real-world situations, they offer exciting suggestions for how to implement this content in new technology, especially in virtual environments. Using these methods, it

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becomes possible to establish important causal mechanisms that operate in rich, representative, real-world situations.

Implications for the Replication Crisis

The failure of many research findings to replicate is of considerable current interest (Bollen et al., 2015). It is widely agreed that no single factor produces replication failure. Instead multiple factors contribute, including weak power, poor methodological practices, problematic statistical procedures, and incomplete reporting policies.

Of particular interest here is the factor of context-sensitivity, where an effect varies as a function of moderator variables present and/or absent. To the extent that important moderators surrounding an effect change, the effect may come and ago. In a recent assessment of this phenomenon, Van Bavel, Mende-Siedlecki, Brady, and Reinero (2016) found that the ability to replicate an effect was related to its context sensitivity. For many effects, their presence depends on specific contextual conditions.

Context-sensitivity has obvious implications for effects developed in idealized laboratory paradigms. Once these effects are embedded in real-world settings, they may no longer occur when new moderators are present. Perhaps this indicates that the effect does not have much real-world relevance. More likely, though, the effect may be important in the real world but depend critically on moderators. As Van Bavel et al. (2016) note, replication failures that result from context sensitivity offer opportunities for better understanding an effect. Not only do we learn about the conditions necessary for producing it, we gain deeper insight into the mechanisms responsible. As we develop an increasingly complete account of the moderators that influence an effect, the ability to predict and understand its presence increases across contexts.

A natural response from the perspective of idealized paradigms is that if an effect does not generalize across contextual conditions, it must not be important. Indeed, this kind of argument has been used to diminish the importance of social priming phenomena that often depend heavily on moderator variables (Barsalou, 2016c; Cesario & Jonas, 2014; Dijksterhuis, van Knippenberg, & Holland, 2014; Higgins & Eitam, 2014; Molden, 2014a, 2014b; Wheeler & DeMarree, 2009). Given the widely acknowledged importance of predictive coding (e.g., Clark, 2013; Friston, 2010; Miller et al., this issue), we might not want to dismiss an important class of social phenomena closely related to predictive coding just because they are diverse and complicated.

Indeed, context-sensitivity may be the norm rather than the exception. Many phenomena believed to be robust across contextual conditions may actually be context sensitive. Consider automaticity phenomena, such as Stroop interference and Simon congruency. Surprisingly, much research demonstrates that these classic automaticity effects and many others reflect current task conditions (Gawronski & Cesario, 2013; Kiefer, Adams, & Zovko, 2012; Lebois, Wilson-Mendenhall, & Barsalou, 2015). To the extent that a phenomenon like automaticity is context-sensitive, it would not be surprising if many other classic mechanisms are as well (e.g., frequency, visual search, repetition priming, syntactic priming, the availability heuristic). Holding out for robust idealized mechanisms may not only be a myth, but an obstruction to understanding how cognition and the brain really work.

An Alternative (and Classic) Strategy for Ecological Assessment and Causal Analysis

As much as I admire Miller et al.'s proposal for combining experimental manipulations with contextually-rich virtual environments using SRD, this approach may not be viable for researchers who lack the necessary technology, skills, and/or interest. A closely related approach has always been available to psychological scientists (and follows naturally from standard psychological methods). Rather than beginning a research program by creating a convenient idealized paradigm in the laboratory, an alternative strategy is to begin in the real world where the phenomena of interest occur. Similar to classic work in biology, chemistry, and physics, new research on natural phenomena of interest begins with observing and describing these phenomena thoroughly and carefully. In psychology, we have many rich methods for performing observation and description, both qualitative and quantitative. There is no substitute for becoming a student of the relevant phenomena and developing a good grasp for how they occur naturally.

In the process, hypotheses about possible mechanisms typically develop, following from the experimental and theoretical acumen at the heart of psychological science. Although these mechanisms could then be tested in rich virtual environments, they could also be examined in classic idealized laboratory paradigms. Because these mechanisms emerged from careful observation and description of relevant real-world phenomena, they have at least some chance of generalizing back to the world in attempts to verify their relevance—more so than mechanisms that only became apparent when looking where the light was good. In this manner, psychological scientists could embrace Miller et al.'s important message about establishing mechanisms that generalize to the real-world, without using virtual environments to do so, whatever their reasons might be.

I hasten to reiterate that virtual environments offer a powerful new and exciting way to approach psychological science. My point is that we should not close off other approaches for establishing mechanisms that generalize to natural environments. SRD complements other longstanding approaches that remain readily available.

Regardless, the challenge is to convince experimental psychologists that establishing generalizable mechanisms is of critical importance. To the extent we continue establishing mechanisms that only explain performance in laboratory paradigms, we will perform research that fails to achieve the high aspirations that Miller et al. set for the field. If we want to perform research that has high impact, we must establish mechanisms that mean something in the world, not just in the laboratory. Otherwise, the general population and its institutions will not notice or care. We can establish generalizable mechanisms with the classic progression of observational, descriptive, and experimental research. We can also establish them using Miller et al.'s SRD approach. If we set ourselves the goal of generalizing mechanisms to important real-world contexts, all these approaches can work together in achieving it.

Capturing an Individual's Situational Experience

To establish a generalizable mechanism, it is necessary to demonstrate that it operates under real-world conditions. To do so, it is first necessary to establish what these conditions are. Miller et al. (this issue) propose one method for doing so: SRD. Another classic example is Brunswickian analysis, as Miller et al. review in some detail (Brunswik, 1947, 1955; Dhami, Hertwig, & Hoffrage, 2004; Hammond & Stewart, 2001).

Inspired by the theoretical perspective of grounded cognition (Aydede & Robbins, 2009; Barsalou, 1999, 2008a, 2009, 2016a, 2016b; Coello & Fischer, 2016a, 2016b; Pecher & Zwaan, 2005), my colleagues and I have developed an additional approach for establishing the rich content of real-world situations. Because this approach is grounded in two dimensions of situatedness—situational experience and the situated action cycle—we refer to it as the *Situated Assessment Method* (SAM^2). We believe that this approach has potential for providing the rich contextual content in important real-world situations that Miller et al. (this issue) champion. I return to this claim after saying more about how SAM^2 works.

SAM^2 was developed as an alternative to standard self-report instruments that use *decontextualized* items to assess an individual difference of interest. To see this, consider an item from the Big 5 inventory that assesses extroversion, "I see myself as someone who is talkative" (Goldberg, 1992; John & Srivastava, 1999). In responding to this item, individuals must abstract over situational experiences to establish a general assessment of how much they agree with it. Similarly consider an item from the brief trait Self-Control scale, "People would say I have very strong self-discipline" (Tangney, Baumeister, & Boone, 2004). Again, individuals must abstract over situational experiences to establish a general assessment. Numerous other self-report instruments similarly ask individuals to respond generally across situations to decontextualized items, including the Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983), the Positive and Negative Affect Schedule (Watson, Anna, & Tellegen, 1988), the Life Satisfaction Scale (Diener, Emmons, Larsen, & Griffin, 1985), the Three-Factor Eating Questionnaire (Lauzon et al., 2004), and the Five-Facet Mindfulness Scale (Baer, 2006). In general, these kinds of instruments reflect the classic problems that Miller et al. (this issue) raise about unsituated research methods.

From the theoretical perspective of grounded cognition, understanding individual differences in a behavior requires taking situations, embodiment, and action into account—establishing the rich contextual content that Miller et al. (this issue) advocate. Decontextualizing the behavior by filtering these features out runs the risk of measuring and representing it incorrectly. SAM^2 offers an approach to grounding the measurement of individual behavior in situations, bodies, and action. Each dimension of situatedness in SAM^2 is addressed next in turn: (1) specific situations, (2) the situated action cycle.

First, when SAM^2 assesses individual differences in a target behavior of interest—such as eating or stress—it assesses the behavior in the *specific situations where it occurs*. Rather than asking individuals to generalize about the behavior across situations without explicitly taking them into account, SAM^2 first identifies relevant situations where the behavior occurs, and then asks individuals to evaluate the behavior in each one. For different target behaviors, such as eating versus stress, the situations sampled can vary considerably, depending on the specific situations associated with each target behavior. In our research so far, the number of situations assessed has ranged from dozens to hundreds, depending on the health behavior of interest. Our stress and mindfulness studies, for example, used 48 situations from 6 stress domains; our habits studies used 80 situations from 10 habits domains; our trichotillomania studies used 52 situations from 7 hair pulling domains; our food studies either used 177 foods from 4 eating situations, or 344 foods from 8 eating situations. In some studies, we have asked participants to generate their own situations, which appears to work comparably to sampling a common set of representative situations from the population of interest. We anticipate that individual sampling will work better in some contexts.

Second, SAM^2 assesses each sampled situation from the perspective of the *situated action cycle*, which contains five basic phases: (P1) the environment, (P2) self-relevance, (P3) affect, (P4) action, (P5) outcome. In the environment phase (P1), agents experience situations that offer affordances for action and trigger habitual behavioral patterns. In the self-relevance phase (P2), entities and events in the environment activate relevant goals, values, identities, norms, etc., often implicitly. Once a situation's relevance for the agent becomes established, it initiates affective states associated with emotion and motivation (P3). In turn, emotion and motivation induce action (P4), ranging from gross bodily movements to eye movements and executive processes. Finally, the actions performed produce outcomes (P5), including reward and prediction error. For the past century, variants of what we are calling the situated action cycle have played central roles in theories of conditioning, goal pursuit, text processing, narrative structure, and conceptual processing (e.g., Baerger & McAdams, 1999; Barsalou, 2003, 2016a, 2016b; Barsalou, Dutriaux, & Scheepers, 2018; Bouton & Todd, 2014; Domjan, 2014; Edson Escalas, 2004; Miller, Galanter, & Pribram, 1960; Newell & Simon, 1972; Reese et al., 2011; Stein & Hernandez, 2007).

SAM^2 samples important features from the situated action cycle for the target behavior of interest. Typically, the choice of these features is strongly influenced by research literatures associated with the behavior. For eating, relevant features include the availability of a food in the environment

(P1), the anticipated healthiness of the food (P2, P5), the affective pleasure of consuming it (P3), the automaticity of consuming it (P4), and many others. For stress, relevant features include the frequency of a stressor occurring (P1), the threat it induces (P2), the arousal that results (P3), the effectiveness of coping behaviors (P4), subsequent rumination (P5), and many others. Once relevant features from the situated action cycle have been established, participants are asked to rate each sampled situation (as described earlier) on each feature. As a result, a rectangular matrix of judgments is obtained that represents important features of the situated action cycle across representative situations from the behavioral domain.

This data set enables a wide variety of descriptive functions that capture the situational richness of a behavioral domain at both the group and individual levels. For each situation, a profile of its features emerges across the situated action cycle that not only establishes rich information about the situation but captures how it is related to other situations. For each individual participant, a profile emerges of the situational features that predict a target behavior of interest, such as establishing motivations for food choice, or factors that induce stress. Although we always observe large individual differences, SAM^2 modeling typically explains about 75% of the variance in an individual's behavior, indicating that it does a good job of capturing these differences. Not only does SAM^2 capture rich situational content, it represents this content from the perspective of each individual participant (along with group-level profiles).

SAM^2 is a flexible tool that can be applied to a wide range of behaviors. To date, we have applied it to common habits (Dutriaux, Clark, Papies, Scheepers, & Barsalou, 2019), eating (Werner et al., 2019), stress (Barsalou, Dutriaux, Hertzog, & Hartley, 2019), trichotillomania (Taylor Browne Luka, Dutriaux, Hendry, Stevenson, & Barsalou, 2019), and mindfulness (Dutriaux, Cleland, & Barsalou, 2019). Across health behaviors, we have consistently found a common pattern of results that reflects SAM^2's ability to capture the rich content of a behavioral domain, although each domain also exhibits unique qualities at a more specific level.

With respect to the Miller et al. (this issue) article, SAM^2's relevance is that it offers a means of measuring rich situational content, similar to the approaches that Miller et al. present. Additionally, SAM^2 is a tool that could be used to map out a domain descriptively before attempting to establish causal mechanisms later, using either idealized paradigms or SRD. In developing applications of SAM^2, we consistently find that it helps identify potential mechanisms and their roles in behaviors of interest. Although the correlational nature of SAM^2 does not establish causal conclusions, the correlational patterns it discovers typically suggest underlying causal processes, which can be subsequently assessed with appropriate methods, such as idealized laboratory paradigms or SRD. Because hypotheses about these mechanisms emerge from careful study of naturally occurring situations, mechanisms verified by subsequent experimental analysis are likely to be generalizable.

The Fuzzy Construct of *Situation*

As Miller et al. (this issue) note, coming up with a clear definition of *situation* is challenging, if not impossible. One approach to resolving this potential issue—inspired by decades of research on concepts and categorization—is to assume that concepts typically do *not* have clear definitions, and are instead represented statistically as prototypes, radial categories, and/or exemplars (Barsalou, 2012; Goldstone, Kersten, & Carvalho, 2018; McRae & Jones, 2013). In classic terms, situations constitute a fuzzy category. Rather than having a clear definition (or even needing one), the construct of *situation* is associated with a set of prototypical features, or perhaps a radially distributed set of sub-concepts for different kinds of situations. It is highly likely that a complex category like *situation,* with so many diverse instances, is not represented definitively but statistically and enumeratively.

If the construct of *situation* does indeed take this form, then it will not be productive to try and account for *all* situations with a single definition or theory. Instead, a more effective strategy may be to focus on subsets of situations that are either theoretically significant or pragmatically important (Barsalou, 2016b; Barsalou, Breazeal, & Smith, 2007). For example, theoretically significant situations are those having an evolutionary history, such as situations associated with eating, tool use, and social interaction. Similarly, pragmatically important situations include situations related to critical social issues such as stress, prejudice, and sustainability. Rather than trying to establish an account of all situations—much less establish the rich content of them all—it might be more productive to establish accounts of theoretically and pragmatically important situations like these (at least initially).

A related strategy is to focus on a subset of situational structure that is of central importance, rather than trying to explain (or capture) all the structure of situations. As illustrated with SAM^2 earlier, it may be useful to simply focus on the core phases of the situated action cycle, including environmental cues, self-relevance, affective states, action, and outcomes. As SAM^2 analyses suggest, much can be accomplished by focusing on core elements of situations, without attempting to capture everything else about the situations of interest.

Much is to be gained by focusing theory and research on situations. As described next, an argument can be made that cognition, affect, and behavior revolve around the accumulation of situational content in memory and its ubiquitous use in intelligent behavior. Rather than abandoning the construct of *situation* because of its complexity and vagaries, perhaps we should embrace it, given everything that can be accomplished by doing so.

Developing comprehensive theory

In setting high scientific aspirations for the field, Miller et al. (this issue) propose that generalizable mechanisms capable of producing social impact must be accompanied by "bigger theory," or what might alternatively be called "comprehensive theory." As Miller et al. note, the partial, more local theories that psychological science typically develops can be useful for specific problems, but do not generate the impact and benefits of more ambitious theories in other sciences.

Most likely, multiple perspectives, systems, and mechanisms must be combined to produce a comprehensive theory. Because no single approach is likely to be sufficient, finding ways to create effective syntheses will be essential. For example, a comprehensive theory might need to include symbolic, cognitive, and affective mechanisms; be implemented in a dynamic statistical architecture; be grounded in the modalities, the body, and the environment; support situated action in both the physical and social environments; integrate systems level mechanisms and networks with the underlying biology of the brain and body (Barsalou, 1999, 2016b; Kiefer & Barsalou, 2013). Miller et al. (this issue) suggest that sophisticated top-down prediction offers one approach to developing comprehensive theory, as exemplified by predictive coding theories (and many other top-down predictive approaches, such as interactive activation models; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982).

No doubt, sophisticated top-down prediction is essential for any comprehensive theory. Again, though, a comprehensive theory most likely requires many perspectives, systems, and mechanisms. Top-down prediction, alone, is not likely not get the job done. A sobering possibility might be that the field is not ready for a comprehensive theory, and may not be for a long, long time. If so, an interesting and important intermediate goal might be to identify the barriers to establishing comprehensive theory at this point, and what we can do about them.

Regardless of whether the field is ready for a comprehensive theory, we might agree that such a theory must explain how the brain acquires and uses rich situational content. To the extent that rich content plays central roles in cognition and behavior, mechanisms for acquiring and using it should be discovered, controlled, and modeled. Situated Conceptualization Theory offers one account of these mechanisms (Barsalou, 2003, 2009, 2016b, 2016c; Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Barsalou et al., 2018; Papies & Barsalou, 2015). According to this theory, the brain is a situation processing architecture that perceives, conceptualizes, and stores rich situational experience in memory. On later occasions, situational memories become reinstated in the situation processing architecture to produce extensive top-down predictions during situated action, implemented as multimodal simulations. The critical elements of this account are addressed next in turn.

Situated Conceptualization

The core assumption of Situated Conceptualization Theory is that the brain evolved to become a *situated processing architecture*, not only to process immediate situations, but to simulate non-present situations in memory, language, and thought. First consider how the situation processing architecture operates in the current situation. As people perceive, cognize, and act in the environment, individual neural systems process different situational elements simultaneously, generating parallel streams of information about the situation. In a given situation, different neural systems process the setting, other agents present, and the self-relevance of everything perceived. Other neural systems implement action in the situation and process its outcomes, such as reward and prediction error. Still other neural systems produce the mentalizing, affect, and interoception that arise over the course of the situation. Each of these neural systems produces a continuous stream of perceptual experiences (qualia) for its respective situational component, together with corresponding conceptual interpretations of it. As each system processes its respective situational component, association areas integrate these local streams of information globally. A coherent perceptual experience of the situation results across situational components, together with a coherent conceptual interpretation, establishing a *situated conceptualization* of the situation.

As a situated conceptualization is constructed, a trace of it becomes superimposed on long-term memory. When a particular type of situation occurs repeatedly, the situated conceptualizations constructed for its instances might be superimposed on memory as a set of individual exemplars, or emerge as an abstraction that covers them. Both exemplars and abstractions may accumulate in parallel (e.g., Barsalou, 1990; McClelland & Rumelhart, 1985).

The process of constructing situated conceptualizations and superimposing them on memory provides a natural account of how rich real-world content becomes established in memory. It further explains how individual differences in situational experience produce individual-specific knowledge that shapes each individual's cognition, affect, and behavior. As different individuals experience different eating situations, for example, they accumulate different populations of situated conceptualizations for eating. As we will see shortly, these different populations later produce different pattern completion inferences to food cues in eating situations, thereby producing individual differences.

Pattern Completion Inference

As the current situation is experienced, it projects onto all situated conceptualizations in memory. The brain attempts to categorize the current situation with respect to previous situations it has experienced. When the most likely and best matching situated conceptualization becomes active (in a Bayesian sense), it categorizes the current situation as a similar type of situation (Barsalou, 2011). On some occasions, the best fitting situated conceptualization might be a specific situational memory; on others, it might be an abstraction that represents a category of repeated situations.

As a situated conceptualization becomes active, it produces inferences about what is likely to occur in the current situation. Based on the process of pattern completion, content in the activated situated conceptualization not yet perceived is inferred as likely to occur. Typically, these inferences occur involuntarily as the situated conceptualization becomes active, with some being conscious and others being unconscious. The primary function of these inferences is to go beyond the information given, as an agent anticipates what is likely to occur in a situation and how to act effectively in it (Bruner, 1973).

As anticipated a moment ago, individual differences in situational experience lead to different pattern completions in new situations. To the extent that different individuals establish different situated conceptualizations in a domain, they later draw different pattern completion inferences when reactivating them in response to the same entity or event. Different experience in a domain leads to different predictions about it. On seeing a box of donuts, for example, some eaters may draw inferences about how tasty eating a donut would be, whereas others might anticipate long-term effects on their body weight and health. From the perspective of Situated Conceptualization Theory, the prediction process is exquisitely sensitive to the specific situational experience that informs it (Barsalou, 2016c). Different populations of situated conceptualizations, together with the different pattern completion inferences that follow from them, constitute the mechanisms that implement these individual differences.

Multimodal Simulation

Finally, Situated Conceptualization Theory assumes that pattern completion inferences are implemented as multimodal simulations across the relevant modalities. Anticipated perceptual predictions about objects and events result from simulations of the relevant perceptual content in visual, auditory, gustatory, and/or olfactory systems (whatever modalities are relevant). Anticipated actions result from simulations in the motor system. Anticipated emotions, motivations, and thoughts result from simulations in affective and mentalizing systems.

Essentially, the multimodal simulation that results from the pattern completion process reinstates the experience of a previous situation in the brain's situation processing architecture. By reenacting the previous situation as a multimodal simulation, the pattern completion process provides a sense of physically being in the situation, acting in it, and responding emotionally. By superimposing the simulated situated conceptualization on processing of the current situation, the pattern completion process guides perception, action, and affective states as the situation unfolds. In this manner, Situated Conceptualization Theory explains how top-down predictions come to guide situated action (Barsalou, 2003, 2009, 2016b, 2016c; Barsalou et al., 2003).

Caveats

Many neural net mechanisms exist for capturing statistical patterns and reinstating them from partial cues, producing pattern completion inferences in the process. In this regard, Situated Conceptualization Theory offers nothing new. What this theory does add, though, is embedding a pattern learning and completion mechanism in a situation processing architecture that supports the situated action cycle. To my knowledge, no such neural net architecture has been specified, much less implemented. This theory further adds multimodal simulation within the situated processing architecture to deliver top-down predictions. Perhaps most importantly, this approach offers a perspective on how rich situational content becomes captured and used to guide cognition, affect, and behavior.

A clear limitation of Situated Conceptualization Theory is that it has not been implemented as a computational model; nor has it been specified in sufficient detail to be implemented. Perhaps the greatest challenge to doing so is specifying each of the individual neural systems in the situated processing architecture that performs perceptual and conceptual analysis of a situational component (e.g., self-relevance, affect, action, outcomes). A further challenge is specifying how these multiple neural systems integrate their outputs to produce a coherent perceptual experience of a situation, together with an integrated conceptual interpretation. In my opinion, we are currently not in a position to specify, much less implement, these systems. If so, and if a comprehensive theory includes something like a situation processing architecture, then we are a long way from developing a comprehensive theory.

Additionally, a comprehensive theory requires specifying many other systems and mechanisms, as suggested at the outset of this section, and they would need to be integrated with the situation processing architecture. Again, to the extent that we are not in a position to specify these processes with any precision, or their integration with the situation processing architecture, we are not ready to develop a comprehensive theory.

Quantum Mechanisms

To develop a comprehensive theory, we may also need to revisit our assumptions about mechanisms. Unrealistic assumptions about mechanisms may be one reason we struggle with their generalizability. Of particular interest here is the common assumption that mechanisms are non-probabilistic (much like mechanisms in classical physics). Specifically, psychological mechanisms are typically assumed to be fixed and constant, operating in the same manner across situations, not varying in form. Consider examples of such mechanisms in cognitive psychology: mechanisms for orienting, detecting, and alerting in attention; mechanisms for executive processing and storage in working memory; conceptual structures and processes in knowledge; rules for phonetics, phonology, morphology, and syntax in language; rules for reasoning and decision making in thought. Typically, these kinds of mechanisms are assumed to operate in a relatively stable manner, taking a constant form across situations. In some instances, variability in a mechanism might be associated with individual differences (e.g., executive and storage processes in working memory). For a given individual, however, the typical assumption is that a mechanism takes a relatively stable form. A mechanism is not characterized as taking different probabilistic forms as it operates over time and is influenced by situational moderators.

Adopting a quantum perspective offers a significantly different way of conceptualizing mechanisms, assuming instead that the form of a mechanism varies probabilistically. Rather than taking a single fixed form, a cognitive, affective, or neural mechanism takes infinitely many forms. Although the expression of the mechanism varies across situations, these expressions have a central tendency that can be viewed as the mechanism's default form. When quantum theory is reduced to classical theory, the default form becomes the classic fixed form of the mechanism. All other factors being equal, the default is the form most likely to emerge when the mechanism is engaged. Importantly, however, contextual moderators also influence the mechanism's expression, increasing the likelihood of a form relevant in the current situation. As a consequence, different contextual conditions drive the mechanism into different contextually-relevant states that depart from the default, at least to some extent (i.e., the default maintains a presence, in the Bayesian spirit of combining the mechanism's prior with the situation's likelihood). The quantum perspective further assumes that a mechanism can be in multiple simultaneous states to differing degrees, and that observing the mechanism affects its measurement, with objective measurement not possible.

The quantum perspective offers a useful lens for examining the generalizability of mechanisms in psychology, cognitive science, and neuroscience. Although important technical applications of quantum theory to cognition exist (Bruza, Wang, & Busemeyer, 2015; Pothos & Busemeyer, 2013; Wang, Busemeyer, Atmanspacher, & Pothos, 2013), the application here is not technical but metaphorical, using the quantum perspective as an interpretive lens for conceptualizing mechanisms.

Several implications follow from a quantum perspective. First, we should *not* assume that the form of a mechanism identified in a laboratory paradigm is the default form (as we often do). To the extent that laboratory conditions are atypical of real-world conditions, the form of a mechanism established in the laboratory is likely to be atypical, not the default. As a consequence, attempts to replicate the mechanism in the real-world may often fail, where it takes a form closer to the default. From this perspective, nonrealistic laboratory conditions must be seen for what they are: Conditions unlike the real world that often produce atypical expressions of mechanisms.

Second, if we want to establish the default form of a mechanism in the laboratory, our attempts should be informed by natural conditions in the real-world. We must first perform something like Brunswickian analysis, SRD, or SAM^2 to establish the real-world conditions under which the mechanism typically operates. To the extent that we subsequently implement these conditions in an idealized laboratory paradigm, we become more likely to establish a form of the mechanism that approximates its default, and that generalizes to real-world situations.

Finally, at least some of the field's current concern about replication failure may result from holding the mistaken assumption that psychological mechanisms are classical, failing to appreciate that they might actually be quantum. If we assume incorrectly that a mechanism takes a fixed form, then we will expect this form to appear consistently across attempts to replicate it. If we had instead adopted a quantum perspective, our expectations would be different. We would be more cautious about expecting mechanisms established in idealized laboratory settings to replicate elsewhere, and we would not be surprised when replication attempts fail. Because the form of a mechanism varies probabilistically, it is likely to take different forms across attempts to observe it, with the observation process itself having effects as it, too, varies.

As mentioned earlier, many other important factors underlie replication failure besides context sensitivity, including weak power, poor methodological practices, problematic statistical procedures, and incomplete reporting policies. No doubt, we need to replace poor research practices with best practices that transform our science. At the same time, if we are dealing with quantum mechanisms, then this needs to be factored into best practices as well. Practice informed by naïve theory is probably not best practice.

An Example: Simulators and Simulations

To illustrate how a mechanism can take quantum forms, consider concepts. Often concepts are viewed as classical fixed structures, taking the form of a definition, a prototypical feature set, a frame, and so forth (Barsalou, 2012; Barsalou & Hale, 1993). Alternatively, a concept can be viewed as an ability or competence that produces an infinite number of conceptualizations about a category of things in the world (Barsalou, 1987, 1989, 1993). The general idea is as follows. As the members of a category are experienced, information about them becomes superimposed on memory as exemplars, abstractions, and other structures. Over time, a tremendous amount of information about the category accumulates in memory. On a given occasion, when information about the category is needed (e.g., cued by a word, perceived instance, or relevant setting), a very small subset of this accumulated information becomes active to represent it—what might be considered a conceptualization of the category. The entire body of accumulated conceptual knowledge for the category never becomes active all at once—the entire "concept" is never fully expressed. Instead, only one specific conceptualization of the category is expressed on a given occasion, from the infinitely many conceptualizations possible.

Barsalou (1999) developed a form of this approach from the perspective of grounded cognition. In this account, the entire body of accumulated knowledge for a category constitutes a *simulator*, and an expression of the simulator on a specific occasion constitutes a *simulation* (also see Barsalou, 2003a, 2008b, 2016a, 2017a). Consider an individual's simulator for the category of hammers. As someone uses a hammer on a specific occasion, brain areas that process the hammer's features become active to represent them in the relevant sensory-motor modalities (e.g., Martin, 2007, 2016), with association areas integrating these modality-specific representations in (e.g., Barsalou, 2016b; Barsalou et al., 2018; Binder, 2016; Fernandino et al., 2016; Simmons & Barsalou, 2003). On each occasion when a hammer is used, a distributed associative pattern becomes established in this manner across relevant brain areas, such as the fusiform gyrus (to process its shape), premotor cortex (to implement action), inferior parietal cortex (to process the action's spatial trajectory), and posterior temporal gyrus (to process the resulting visual motion). Integrative associative patterns may further become established in temporal, parietal, and frontal cortices. The resultant distributed pattern that is constructed and superimposed on memory is essentially a situated conceptualization, as discussed earlier. Over the course of many learning episodes with hammers, an increasingly entrenched associative network develops across the brain that accumulates the aggregate effects of superimposing hammer information in relevant neural systems. The sloppy, difficult-to-localize network that evolves into a hammer simulator essentially implements a hammer concept, as I've been defining it, given that it contains accumulated information about hammers that can be used to represent them in their absence.

Once a hammer simulator exists, it produces multimodal simulations of hammers in relevant situations, via the pattern completion process described earlier. When a cue in the current situation activates the simulator (e.g., a perceived hammer, the word "hammer," a relevant hammer setting), a very small subset of the simulator's distributed network becomes active—a simulation—to create one possible representation of a hammer. As different subsets of the hammer simulator become active across situations, different simulations express different conceptualizations. In principle, multiple simulations could be simultaneously active, or partially active, within the simulator at a given moment.

Thus, a simulator is a quantum mechanism that expresses itself in infinitely many ways. Although similarities are likely to emerge across simulations, differences are likely to emerge as well. Much research on concepts documents the extensive variability in how the 'same concept' is represented across situations (Barsalou, 1987, 2016b, 2017b; Casasanto & Lupyan, 2015; Connell & Lynott, 2014; Lebois et al., 2015; Yee & Thompson-Schill, 2016). Additionally, a central tendency exists across possible simulations that constitutes the simulator's default. At the classical level, the simulator's default simulation is the concept. At the quantum level, the simulator is the concept, expressing itself in infinite ways across situations. Furthermore, attempting to measure the simulator, or one of its simulations, influences the simulation expressed.

Applying this quantum account of concepts to specific experiments and their replications is an interesting exercise. Imagine that an experiment on conceptual processing includes multiple trials when the word "hammer" is presented. For a given individual, the hammer simulator becomes active in at least somewhat different ways across trials, given that it is a quantum mechanism. The large variability often observed for a stimulus item within an individual participant is consistent with this quantum account. Further imagine that the hammer simulator differs across individuals as a function of each individual's unique population of hammer experiences. Finally, imagine that the specific situation where the experiment is performed further influences how each individual's hammer simulator operates. The resulting measurements obtained for hammer trials (e.g., RTs) vary widely as a function of the trial, the individual, and the experiment. Because hammer simulators are quantum mechanisms, considerable variability results in hammer measurements when aggregated at both the individual and experiment level. As a further consequence, when a replication is run, even minor differences in the participants sampled and in the experimental situation can produce aggregate measures that vary significantly from the original experiment. From this perspective, it is a wonder that replications occur (but perhaps a testament to simulators having similar defaults).

An interesting exercise might be to establish similar quantum accounts for other classic cognitive mechanisms, including those mentioned earlier for attention, working memory, language, and thought.

Generalizing Quantum Mechanisms

How do we approach the issue of a mechanism's generalizability from the quantum perspective? Because a mechanism takes so many forms across situations, perhaps it has no generalizability. If, however, we specify that a specific kind of situation is of interest, we can then ask whether a mechanism generalizes across instances of this situation—essentially the construct of *representative design* in Brunswickian analysis. For example, when a particular real-world situation is of interest, we can initially assess the mechanism in it, and then later assess whether we can replicate the results obtained in instances of the situation. In other words, generalizability no longer applies to whether the mechanism is observed across all possible situations, but to whether it expresses itself similarly in the same kind of situation.

From this perspective, mechanisms established in idealized laboratory paradigms will most likely generalize to real-world situations when these particular real-world situations informed the laboratory paradigm. When the real-world was not consulted, the quantum states of these mechanisms observed in the laboratory may fail to replicate when unanticipated real-world moderators drive them into different states. As these examples suggest, generalizability becomes limited to replicating a mechanism's behavior under similar situational conditions. From the quantum perspective, it is unrealistic to assume that a mechanism will generalize across all contexts, always expressing itself in the same way. If understanding a mechanism's many quantum forms is of interest, it may have to be assessed across many diverse situational conditions.

Conclusion

The core issue at stake here is the ability of psychological science to establish generalizable mechanisms. Rather than establishing mechanisms that only explain performance in the laboratory, our science needs to establish mechanisms that explain cognition, affect, and behavior in the real world.

Are experimentalists in psychological science ready to shift their attention to generalizable mechanisms? Can they can develop a passion for doing so?

What might motivate a passion for establishing generalizable mechanisms? Miller et al. (this issue) suggest an increased likelihood of Nobel Prizes. No doubt being honored in this way says a lot about what an individual and a field have accomplished. Perhaps, though, we should let such awards fall as they may and focus on more important motivations.

Most basically, we should be motivated by developing a successful science. If psychology is truly a natural science, our primary motivation should be to understand natural phenomena in the world associated with intelligence and behavior. Nothing should gratify us more than understanding and explaining critical natural phenomena. As I mentioned at the outset, though, humans did not evolve to make the work of experimental psychologists easy. Arguably, no science faces greater challenges in explaining its natural phenomena than psychology, along with related disciplines in the cognitive sciences and neurosciences.

The challenges to explaining natural intelligence and behavior may be so overwhelming that they drive us to only look where the light is good. As a result, we become satisfied to simply explain laboratory performance, having little concern with whether the resultant explanations generalize to the natural phenomena of interest. If psychological science and related sciences are to succeed, however, we must learn to avoid retreating from natural complexity into the idealized world of the laboratory. We must instead decide that we are up to the challenge of taking on natural complexity. Although daunting issues await, there is no other way to build a successful *natural science* (as opposed to a contrived and artificial one). It is perhaps worth noting that natural complexity is likely to be replete with clues that guide the discovery of generalizable mechanisms. Maybe we just need to spend more time looking?

No further motivation is required to take on natural complexity. Nevertheless, other important reasons exist for shifting our attention from the laboratory to the world. Our planet faces tremendous challenges associated with sustainability, climate change, nationalist threats to democracy, widespread stress, high rates of mental illness, shocking rates of obesity, and so forth. Human cognition, affect, and behavior lie at the heart of these problems. Intervening on them successfully requires establishing generalizable mechanisms that increase our ability to understand what is happening, and what we can do to implement effective behavior change.

Our survival as a species obviously depends on many factors. Establishing generalizable mechanisms that underlie the challenging problems we face might be a step in the right direction.

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