A Critical Deconstruction of Quantum Cognition and Usability in Psychology

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Abstract. The paper "What Is Quantum Cognition, and How Is It Applied to Psychology?" by Busemeyer and Wang (2015) introduces the concept of quantum cognition as a framework for understanding human cognition in psychology. This critical analysis aims to evaluate the key arguments and contributions presented in the paper.

The authors propose quantum cognition as a research program that utilizes mathematical principles from quantum theory to explain various aspects of human cognition, such as judgment, decision-making, concepts, reasoning, memory, and perception. They emphasize that quantum cognition does not focus on whether the brain is a quantum computer, but rather utilizes quantum theory as a fresh conceptual framework and a set of formal tools for elucidating empirical findings in psychology.

The authors specifically highlight two quantum principles, complementarity, and superposition, to demonstrate the potential of quantum cognition as a theoretical direction for psychology. Complementarity suggests that some psychological measures need to be made sequentially, where the context generated by the first measure can influence responses to the next one, leading to measurement order effects. Superposition suggests that certain psychological states cannot be defined by definite values, but rather encompass a range of potential expressions.

This critical review will analyze the strengths and weaknesses of the arguments presented by Busemeyer and Wang, evaluate the evidence supporting their claims, and discuss the implications of quantum cognition for the field of psychology.

Keywords: Quantum cognition, human cognition, decision making, complementarity, superposition, order effects, interference effects, critical analysis.

1 Introduction to Quantum

Quantum mechanics, a fundamental branch of physics, investigates the behavior of matter and energy at the most minor scales. It provides a theoretical framework that departs from classical physics, introducing intriguing concepts such as wave-particle duality, superposition, and quantum entanglement (1-3). These concepts fundamental-

R. Somashekhar et al. (eds.), *Proceedings of the International Conference on Advances in Nano-Neuro-Bio-Quantum (ICAN 2023)*,
Advances in Intelligent Systems Research 69,
https://doi.org/10.2991/978-94-6463-294-1_3

ly challenge our classical intuitions and lay the foundation for a new understanding of the microscopic world.

The development of quantum theory in the early 20th century revolutionized our comprehension of nature. It began with Max Planck's groundbreaking work on black-body radiation, where he introduced the revolutionary notion of quantized energy (1). This concept was further supported by Albert Einstein's elucidation of the photoelectric effect, which demonstrated the particle-like nature of light (2). Niels Bohr's quantum model of the hydrogen atom in 1913 provided a new understanding of atomic structure by incorporating quantized electron orbits and the emission and absorption of discrete energy levels (3).

Quantum mechanics challenges the deterministic nature of classical physics, introducing the concept of superposition, where particles can exist in multiple states simultaneously. This leads to the intriguing phenomenon of quantum entanglement, where particles become inseparably linked, regardless of the distance between them. These phenomena have been experimentally verified through numerous groundbreaking experiments, including the famous double-slit experiment and Bell's theorem.

The implications of quantum mechanics extend far beyond theoretical understanding. It has led to remarkable technological advancements, such as the development of quantum computing, which holds the potential for exponentially faster computation, and quantum cryptography, offering unprecedented levels of security in communication systems.

2 Extending to Other Disciplines

The utilization of concepts from quantum physics in the study of phenomena beyond the realm of physics has gained significant attention in recent years. The non-deterministic nature, superposition, and entanglement principles inherent in quantum mechanics have sparked curiosity among scholars seeking to explore their potential applications in other scientific domains.

2.1 Quantum Brain Dynamics:-

Quantum physics concepts have been integrated into neuroscientific models to explain neural oscillations, synaptic plasticity, and information processing (4). These models propose that quantum processes at the cellular and subcellular levels contribute to the brain's functioning, offering new insights into cognitive processes, perception, and consciousness.

2.2 Quantum Cognition:-

Quantum-inspired models have been developed to account for cognitive phenomena that classical models struggle to explain, such as decision-making under uncertainty, concept formation, and the emergence of cognitive biases (5). These models provide a fresh perspective on the nature of human cognition and offer potential explanations for complex cognitive phenomena observed in psychology.

3 Introducing Busemeyer and Wang's (2015) take on Quantum Cognition

In the realm of cognitive psychology, understanding the intricate workings of human cognition has been a longstanding pursuit. Traditional approaches have often relied on classical theories and models to explain cognitive processes such as judgment, decision-making, concepts, reasoning, memory, and perception. However, a novel research program called quantum cognition has emerged, which offers a fresh perspective by utilizing mathematical principles derived from quantum theory as a framework to unravel the complexities of human cognition.

The paper titled "What Is Quantum Cognition, and How Is It Applied to Psychology?" authored by Jerome R. Busemeyer and Zheng Wang (2015) (6) delves into the realm of quantum cognition, exploring its application in psychology and its potential to provide insightful explanations for puzzling empirical findings. The paper presents a compelling argument for the adoption of quantum theory as a conceptual framework and a set of formal tools, distinct from investigating whether the brain operates as a quantum computer.

In this paper, the authors focus on two fundamental quantum principles—complementarity and superposition—to illustrate why quantum cognition holds promise as a captivating theoretical direction in psychology.

Complementarity suggests that certain psychological measures need to be conducted sequentially, with the context generated by the initial measurement influencing subsequent responses. This concept challenges the traditional notion of isolated measurements and highlights the interconnectedness of cognitive processes.

The second principle explored is superposition, which posits that some psychological states cannot be confined to definite values. Instead, within the framework of superposition, these states encompass a multitude of potential values. This perspective introduces a new way of understanding the inherent variability and flexibility within cognitive processes, questioning rigid categorization and inviting a more nuanced comprehension of human cognition.

By integrating these quantum principles, the authors argue for a coherent and comprehensive explanation of divergent and perplexing phenomena observed in psychology. Through a careful examination of empirical evidence, they demonstrate how complementarity and superposition work in tandem, offering a fresh perspective on cognitive phenomena that have long eluded traditional explanatory frameworks.

As readers embark on this critical review, we will evaluate the paper's arguments, methodologies, and supporting evidence to assess the strengths, limitations, and overall contributions of the quantum cognition research program to the field of psychology. By critically examining the paper's findings, we aim to gain a deeper understanding of how quantum cognition sheds light on the intricacies of human cognition, offering innovative insights and potential solutions to enduring questions in psychology.

4 Segregating Quantum from Classical

In their work, firstly, they (7) explore the differences between classical and quantum models of cognition. They argue that traditional cognitive theories, rooted in classical computational logic, have shaped the field for decades. These theories rely on commonly accepted assumptions, such as commutative and distributive axioms, which are taken for granted. However, the authors propose that quantum theory provides an alternative framework that challenges these classical assumptions.

The authors use the example of judgment and decision-making regarding guilt and punishment to illustrate the disparities between classical and quantum models. Classical logic assumes that the order of considering propositions does not matter, while quantum theory recognizes that certain questions, such as guilt and punishment, are complementary and require sequential examination. This sequential evaluation generates context that influences subsequent responses. Moreover, quantum theory defies the distributive axiom, allowing for superposition states where decisions regarding punishment can be made while remaining uncertain about guilt.

While their analysis raises thought-provoking ideas, it is important to critically evaluate their arguments and consider the challenges and limitations inherent in the application of quantum principles to psychology.

One potential concern with the authors' analysis is the oversimplification of classical cognitive theories. By characterizing classical models as solely based on the commutative and distributive axioms, they overlook the rich and diverse range of theoretical frameworks and computational models within classical cognitive psychology. This oversimplification undermines the complexity and depth of classical approaches and may lead to an unfair portrayal of their limitations.

Classical cognitive theories often assume that decision-making is a rational and logical process based on the evaluation of available options and the selection of the most favorable choice (7).

However, research in decision neuroscience has shown that decision-making is influenced by various factors, including emotions, biases, and heuristics. Neuroimaging studies have demonstrated the involvement of brain regions such as the ventromedial prefrontal cortex and the amygdala in emotional decision-making (8). These findings suggest that emotions play a significant role in shaping our decisions, challenging the purely rational assumptions of classical models.

Moreover, behavioral economics has highlighted the presence of various cognitive biases and heuristics that systematically affect decision-making. These biases, such as the framing effect (9) or the availability heuristic (10), deviate from the rational decision-making assumptions and demonstrate the complexities involved in real-life decision scenarios.

Furthermore, the authors' presentation of quantum principles as alternatives to classical assumptions lacks a thorough discussion of the empirical evidence supporting their claims. While they highlight the concepts of complementarity and superposition, it remains unclear how these principles can be effectively applied to empirical phenomena in psychology. The authors predominantly rely on theoretical arguments rather than providing substantial empirical support for the existence and relevance of quantum effects in cognitive processes. This lack of empirical grounding limits the practicality and applicability of quantum cognition as a comprehensive explanatory framework.

Another critical aspect to consider is the potential for misinterpretation or misapplication of quantum principles in psychology. Quantum theory was originally developed to explain phenomena at the quantum mechanical level and may not be directly translatable to complex cognitive processes. Applying quantum principles to psychology requires careful consideration and validation to ensure that the borrowed concepts align with the nature of psychological phenomena. The authors do not sufficiently address the challenges and caveats involved in translating quantum principles into a psychological context, which raises concerns about the validity and reliability of the proposed quantum cognitive framework. Lastly, the authors' presentation of quantum cognition as a promising new theoretical direction for psychology overlooks the ongoing debates and criticisms surrounding the field. Quantum cognition remains a highly controversial and debated topic within the scientific community. Critics argue that the application of quantum principles to cognition lacks a solid theoretical foundation and that alternative explanations rooted in classical models can account for observed phenomena more effectively. Busemeyer and Wang's paper does not adequately address or acknowledge these counterarguments, leaving their argument one-sided and potentially biased.

5 The Argument on Order Effects

The authors discuss the presence of order effects in psychological studies and propose that these effects can be explained by the quantum principle of complementarity. They introduce the concept of quantum question (QQ) equality as a precise prediction derived from this principle. The QQ equality states that the difference between the probability of answering "yes" to Question A and then "no" to Question B and the probability of answering "no" to Question B and then "yes" to Question A is equal to the negation of the difference between the probability of answering "no" to Question A and then "yes" to Question B and the probability of answering "yes" to Question B and then "no" to Question A. The authors provide evidence supporting the QQ equality across a wide range of field experiments involving national representative samples in the United States.

The authors' analysis of order effects in psychology and their application of the quantum principle of complementarity to explain these effects is intriguing. By introducing the concept of quantum question (QQ) equality, they provide a precise and parameter-free prediction about the pattern of order effects. This prediction represents a strong test of their quantum cognition theory. The authors also present empirical evidence supporting the QQ equality across a large number of field experiments.

However, it is important to note that the application of quantum principles to psychology is still a relatively new and controversial approach. Critics argue that the observed order effects can be explained by more traditional cognitive processes, such as priming or response biases, rather than invoking quantum concepts. Additionally, some researchers question the validity and generalizability of QQ equality, highlighting the need for further replication and cross-cultural studies.

Furthermore, the authors do not discuss potential alternative explanations for the observed order effects or address the limitations of their quantum cognition framework. Future research should aim to compare and contrast quantum cognition with alternative theories and consider alternative explanations for order effects in psychological studies.

One example that highlights the need for critical evaluation of quantum cognition is the phenomenon of priming in decision-making tasks. Priming refers to the influence of prior stimuli on subsequent behavior or judgments. It has been widely studied in cognitive psychology and has shown consistent effects on decision-making processes.

Critics of quantum cognition argue that the observed order effects, which the authors attribute to complementarity, can be explained by priming effects rather than invoking quantum principles. For example, in a study by Dijksterhuis and van Knippenberg (1998) (11), participants were primed with words related to either intelligence or politeness before engaging in a decision-making task. The results showed that participants primed with intelligence-related words made more rational and logical decisions, while those primed with politeness-related words made decisions based on social considerations.

In this case, the observed order effects in decision-making can be attributed to the priming of specific concepts and associated cognitive processes, rather than relying on quantum principles. This highlights the importance of considering alternative explanations grounded in traditional cognitive psychology when examining the factors influencing decision-making and order effects.

Therefore, while the application of quantum principles to explain order effects in psychology is intriguing, it is essential to critically evaluate alternative explanations, such as priming effects, and conduct further research to determine the specific mechanisms at play. This demonstrates the need for a comprehensive and nuanced approach when analyzing the contributions of quantum cognition to understanding cognitive phenomena.

6 The Argument on Interference Effects

In their argument about evidence for quantum cognition, the authors delve into interference effects in psychology. Interference effects occur when the probability of an event estimated alone differs when considered along with another event, violating the classical law of total probability. The authors present a specific experiment conducted by Busemeyer, Wang, and Lambert-Mogiliansky (2009) (12) as an example. The experiment compared the predictions of a quantum model and a Markov model. While the Markov model predicts adherence to the law of total probability, the quantum model predicts interference effects, indicating a violation of the law.

The results of the experiment support the predictions of the quantum model, showing a significant deviation from the law of total probability and the occurrence of interference effects. The categorization-then-decision condition revealed lower probabilities of a specific action compared to the decision-alone condition. According to the quantum model, participants in the decision-alone condition could remain in a superposition state regarding the category, allowing interference between different thought paths. In contrast, the categorization task in the categorization-then-decision condition forced participants to collapse the superposition onto a particular category, eliminating interference and altering the probability of the action.

To address potential criticism, the authors refute the notion that the quantum model's superiority in fitting data is solely due to its complexity. They cite a study where the quantum model was compared to a successful traditional decision model using Bayesian model comparison. The results overwhelmingly favored the quantum model, suggesting that it provides a more robust account of empirical data, not merely due to complexity but due to its explanatory power.

The authors present evidence for quantum cognition by discussing interference effects in psychology and their comparison to classical Markov models. They highlight that interference effects, violations of the classical law of total probability, have been observed in various experiments across different domains. They present an example study by Busemeyer, Wang, and Lambert-Mogiliansky (2009) (13), which compared the predictions of quantum and Markov models in decision-making.

While the authors offer empirical support for the quantum model's ability to account for interference effects, it is important to critically analyze this argument. Decision-making is a complex process influenced by various factors, such as cognitive biases and contextual influences, which may not necessarily align with the assumptions and predictions of a quantum model. Furthermore, the comparison of quantum models to classical models is a challenging task, as both approaches have their own strengths and limitations.

For instance, the widely known Prospect Theory by Kahneman and Tversky (2013) (13) provides a comprehensive account of decision-making under risk and has been successful in explaining various decision phenomena. It is essential to critically examine the unique contributions and explanatory power of quantum models in decision-making compared to established theories like Prospect Theory.

7 Applications of the Quantum Cognitive Model

To explain paradoxical findings in psychology involving conjunction fallacy, the quantum theory works for decades. Tversky and Kahneman (1973) (10) explained the story of the hypothetical person of Linda to demonstrate the quantum theory in light of conjunction fallacies. But how can we apply the quantum theory to explain these hypothetical findings? Reviewing the finds of this research it is revealed that, the researcher emphasized conjunction and disjunction fallacies to explain the quantum cognitive model including 'interference effect', 'asymmetric similarity judgments (14), and 'irrational decision making' (15).

Daniel Kahneman and Amos Tversky did huge research on the error of human reasoning and explain the conjunction fallacy with a Mental Model. They discovered that people make logical fallacies when they face vague and familiar information. This kind of fallacy can be based on irrational beliefs that are not reality-based. In explaining conjunction fallacy they introduce the concept of biases based on wrong or false belief when two conjunctive information or events are more probable than one of the events.

In this mental model, they introduce the consecutive concept of probability, base rate, and representativeness. When one fails to account for low base rates, representative biases occur. Accordingly, conjunction fallacies occur when there is a higher probability of occurring an event with higher specificity. Despite logicians' and statisticians' disagreement about probability though it can be said that assigning probability helps a person to make the degree of belief about one action and communicate with others.

8 Conclusion

Busemeyer and Wang's (2015) (6) article "What Is Quantum Cognition, and How Is It Applied to Psychology?" describes quantum cognition as a research field that makes use of mathematical concepts from quantum theory to explain various aspects of human cognition in psychology. It emphasises that quantum cognition uses quantum theory as a conceptual framework and formal tools for explaining empirical discoveries in psychology rather than focusing on whether the brain is a quantum computer. To illustrate the possibilities of quantum cognition, the authors focus on two quantum principles: complementarity and superposition. The objectives of this critical analysis are to review the arguments made by Busemeyer and Wang, evaluate the data that supports them, and talk about the consequences of quantum cognition for psychology.

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