Belief updating and rumination: a quantum perspective

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This is a brief article about psychology (specifically the psychology of belief updating and rumination/ ambivalence, that we shall explain shortly). So, what does quantum theory have to do with psychology? Quantum *mechanics* is well known in physics. In fact, quantum mechanics is the basis for much of the technologies that have transformed our lives over the last few decades (think of lasers and computers!). So, how can we propose that a theory of physics is relevant in psychology?

 Quantum mechanics is a theory of physics and the vast majority of psychologists, biologists etc. think it is irrelevant to the study of the mind (and the brain). However, the pioneering physicists who developed quantum mechanics also developed a theory of probability, which we call quantum probability theory (quantum theory for short). A probability theory is simply a set of rules for how to assign probabilities to events. For example, if I am interested in the likelihood that the sun will shine tomorrow, I would express this as a probability. I might say something like “it is likely that the sun will shine tomorrow” or “there is no way on earth the sun will shine tomorrow, because it is autumn and we are in London”. These probabilities can be expressed in more quantitative forms, e.g., in numbers, for example, I could say there is a 30% probability that the sun will shine tomorrow (the interpretation of such a 30% is not entirely straightforward, but we can assume that it means something like out of a 100 days like this one, in about 30 of them I expect that the sun will shine tomorrow).

 The best known and most widely used probability theory is the so-called classical or Bayesian probability theory (henceforth classical theory for short). Classical theory exemplifies all common intuitions about probability. For example, in order to compute probabilities we just enumerate relevant instances. How likely is that the sun will shine tomorrow? I just need to count the number of days like today/ tomorrow on which the sun would shine vs. not shine over a relevant period, say the last 10 years. If I roll a six-died die, what is the probability that I will obtain a 6? If the die is fair, all I need to do is count all relevant possibilities (there are six possible numbers) versus the ones I am interested in (there is only one possibility that I am interested in, that the die will produce a 6). How likely is that I will be successful in my job interview? Here it is a little harder to enumerate relevant instances, however, some powerful theoretical results in classical theory essentially show that the same ‘kind’ of probability is still produced.

 The most obvious question is then why is classical theory not suitable for physics (and why is it not suitable for psychology). Regarding physics, the scientists who established quantum mechanics discovered the physical phenomena they were interested in were just too weird for classical theory. There were many empirical results (concerning microscopic particles) which forced a departure from classical intuitions regarding probability and the development of a new theory of probability, quantum (probability) theory. Quantum theory, together with relevant physical principles, is quantum mechanics. Regarding psychology, the answer is exactly the same: the scientists who established the quantum cognition research programme were motivated by empirical findings which were just too weird for classical theory. Quantum theory, together with relevant psychological principles, have produced cognitive theories which take attempt to explain the principles of classically paradoxical results.

 We will give you just one such example, from two famous researchers, Tversky and Kahneman (the latter received the Nobel prize in economics, for work they both did in relation to utility theory). Consider a hypothetical person called Linda, who is described very much like a feminist and not at all like a bank teller. Imagine also that you live in the early 80s when this pioneering experiment was run, so please suppress for the minute our modern conceptions regarding feminism and professions! Suppose you are asked to consider various statements about Linda. Would you say ‘Linda is a bank teller’ is more or less probable compared to ‘Linda is a bank teller and a feminist’? Most individuals would consider the latter as more probable. However, according to classical theory, the latter cannot be more probable than the former. Imagine lots of lots of possible Lindas, such that some of them are consistent with the property of ‘bank teller’ and some of them with the property of ‘feminism’. It seems clear that we cannot have more Linda’s consistent with both properties, than with either individual property: it is like saying that the statement ‘roll a 5 and a 6’ is more probable than the statement ‘roll just a 6’. Think of rolling the die 100 times and it is immediately obvious that the so-called conjunction cannot be more probable than either individual event.

 So it looks like we are sometimes incorrect when we assess the probabilities of everyday possibilities? Not if one considers the same Linda problem from the perspective of quantum theory. Quantum and classical theory are different sets of rules for how to evaluate probabilities. So, something that is incorrect in quantum theory could be correct in classical theory and vice versa. In quantum theory, it can be possible to have ‘Linda is a bank teller and a feminist’ more correct than ‘Linda is a bank teller’, *if* the characterizations of Linda as feminist and bank teller are *incompatible*. Incompatibility is the key difference between quantum and classical theory; it is a technical term employed in the former. Incompatibility means that the two properties are such that accepting one creates a unique perspective for the other. For example, being asked whether Linda is likely to be a bank teller may seem unlikely, given our initial knowledge of Linda. However, if asked whether Linda is likely to be a feminist and a bank teller, the consideration that Linda is a feminist (very plausible) provides a different viewpoint as to whether she may be a bank teller too. Essentially the bank teller question is different in isolation vs in the context of other incompatible questions, and it is this strong contextuality in quantum theory which allows coverage of such results.

 So far we have considered the ideas that quantum theory is essentially a probability theory, but suited better to certain results in physics or psychology which appear classically paradoxically. This does not mean that classical theory should be rejected: on the contrary, in both physics and psychology, classical theory is often the basis of several successful theories. However, we believe that a complete approach to understanding human behavior must involve both classical and quantum theory.

 Another area which motivates the need to include quantum theory is one of the two aspects of cognition we will consider here, belief updating. Belief updating is about how we update our, well, beliefs, given some information. Suppose we would like to estimate the probability that it will tomorrow. It is autumn and you have some expectations of whether it is likely to rain or not; this is your initial or prior belief. But then you look out of the window and receive some information, say it is really sunny. How does this new information change your belief? Belief updating is a key aspect of human cognition: it underlies all learning and most inference, whether scientific or concerning everyday questions and possibilities. So, how do humans do it?

 You will not be surprised to hear that both classical and quantum theories incorporate rules for belief updating, but that these rules are different. Classical theory involves the famous Bayes’s law. Quantum theory involves the less famous, but equally important, Luder’s law. In order to explain the difference between the two, consider a hypothetical crime story. Some jewels went missing from the household of John and Jane, belonging to Jane, and there are various possible suspects, the some neighbors who happened to visit John and Jane very recently, a cleaner, a gardener, and a person the neighborhood who has had problems with the police in the past. This initial information was created so that some individuals would be beyond suspicion, such as John, while others considered fairly likely suspects. Consider now some additional information, for example, that John has a severe gambling problem and owed a lot of money. For most human participants, this new information leads to an updated belief that John is the most likely suspect.

 So, the behavior we are interested in modelling is the change from a prior belief that John is a very unlikely suspect to a posterior belief that John is the most likely culprit. Interestingly, it is not possible to do so with the belief updating rules embodied in classical theory! The reason is that belief updating in Bayes’s law is constrained in a certain way, so that it precludes large changes in beliefs. This is an interesting feature of classical theory, which has been known for a while, but its implications for whether it matches well human cognition have only recently been explored. By contrast, belief updating in quantum theory does not suffer from analogous limitations: with Luder’s law, very low priors (even a zero probability) can be updated to a high belief, if the provided evidence is strong enough. Overall, we think that an understanding of the way humans updates their beliefs requires a consideration of both classical and quantum rules for belief updating.

 Belief updating is one aspect of the psychological processes which underpin human decision making. An alternative, related to approach this issue involves a consideration of the dynamics of human decision making. Such dynamics clearly involve a part of belief updating; additionally, they provide a finer focus on the actual moment-to-moment changes which eventually produce a decision (or a crystallized belief etc.). The second aspect of cognition we will consider here concerns our intuition that, in some cases at least, it appears that we go through a process of rumination or ambivalence. Consider an everyday problem along the following lines: it is Saturday morning and you decide to go to the shops. You are looking to buy some clothes, but you are unsure of what exactly. You find a pair of trousers on sale you are tempted by; you also see a jumper which would go nicely with some of the shirts you have. In such a situation, you have a choice between two alternatives that are poorly matched, so that it is difficult to compare them along equivalent dimensions. Put differently, if you were looking to buy a particular movie and consider different retailers, there are only two dimensions you might be interested in: price and speed of delivery. So, it would be very easy to compare different retailers. The example of the shopping trip illustrates a case of what we would call ‘complex’ decision making; each option has some advantages and disadvantages, but you cannot really compare the advantages of one option with the ones of the other.

 In such cases of complex decision making, we seem to have an intuition of back and forth, that is, a feeling of preferring one option before reversing to prefer the other before reversing again etc.; this intuition of back and forth is what we characterize as rumination or ambivalence. Here the modelling options are more varied than primarily a contrast between quantum and classical theory. We will just describe the key characteristics of quantum theory, which we think are particularly well suited to rumination. With the so-called open systems quantum dynamics, there is often a characteristic pattern of initial oscillation, followed by gradual quenching of the oscillations and stabilization. This pattern matches the intuition of what happens when we are ambivalent: initial back and forth, followed by a steady state reflecting our final opinion. Here, it is harder to further illustrate why we think quantum theory provides a suitable descriptive framework, without more detailed consideration of the technical characteristics of the different available modelling options. However, we hope that at the very least the intuition of a match between ambivalence intuition and the typical pattern in open systems quantum models would ring true and appropriate.

 In summary, quantum theory has potential for revolutionizing our perspective and scientific approach not just in physics but in all cases where there is a divergence between classical theory and experimental results. In psychology there have been several such examples, which have motivated the application of quantum theory and the creation of quantum cognitive models. Quantum cognitive models complement classical ones in the cases where it appears that human behavior involves, for example, contextual questions or properties. We briefly considered two recent applications of quantum theory, relating to belief updating and rumination/ ambivalence.