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AJP Report 1: Reject publication

I have read the manuscript "A card game for Bell's theorem and its loopholes". The goal of the paper is to present a simple card game from which students can learn the impossibility of achieving the sorts of correlations that are forbidden according to Bell's theorem... and perhaps also understand, by figuring out how to "cheat" to win the game, several loopholes associated with the theorem and/or the associated experiments. I enjoyed reading the paper and applaud the general concept of trying to convey Bell's theorem to students in the form of a simple game. But there are several reasons why I think the paper doesn't quite rise to the level needed to warrant publication in AJP. I describe these below.

First, there is a lot of confusion about what Bell's theorem means/proves, and (at best) this paper doesn't help address those confusions. (At worst, it adds to the inertia of the confusions.) I have in mind here things like the paper's first sentence, which says (vaguely and non-commitally) that Bell's theorem proves "that the laws of physics are not constrained to obey ... intuitive or common notions." There is confusion/controversy, though, about what notions those are, and I would expect newly-published papers on Bell's theorem to be more explicit about this. Another similarly off-putting remark is the following: "Since entanglement is so successfully modelled by quantum mechanics, one can argue that there is no need for a mechanism that 'explains' it." The difference between a mere "model" and an "explanation" is not exactly clear. But the frustrating thing here is again just that the authors remain completely vague about what is at stake. Is it, as many have claimed, the concept of determinism? Or "hidden variables" generally? Or "local causality"? The fact that the authors don't take (and, as necessary, defend) a position on the meaning of Bell's theorem is not necessarily a fatal flaw with the paper since that is not what the paper is all about, but the fact that the ultimate implications of the idea illustrated by the game remain completely unspecified, does seem to significant detract from the authors' aims (and, in particular, would seem to undermine students' motivation to care about the topic).

Another point that detracts from the pedagogical value of the recommended game, at least for me, is that it is not perfectly parallel to the physics experiments (testing Bell's inequalities) that it is supposed to illuminate. The authors acknowledge this, e.g., when they explain that "the card game reverses roles regarding probability: Instead of the investigators attempting to ascertain the photons' so-called hidden variables, the players are acting as particles attempting to win the game by guessing the measurement angles." Similarly: "a penalty must be deducted from the partners' score whenever they are caught using a forbidden strategy..." Again, the fact that the game doesn't perfectly mirror the structure of the real experiments is not necessarily a fatal flaw, but the differences do detract from the ability of the game to really illuminate, for students, what it's meant to illuminate.

Third, I worry that the things about Bell's theorem (and the associated experiments) that are actually difficult to understand (by which I largely have in mind the questions, referred to above, about exactly what minimal set of assumptions gives rise to Bell's inequality, but then also various details about the structure of the experiments and how those relate to the assumptions) are not illuminated by the card game. Instead, the card game focuses

exclusively on the purely statistical aspects of deriving the inequality -- aspects which, in my experience, are the least controversial and easiest for students to understand properly. The authors seem to sort of acknowledge this when they write, in explaining the solitaire version of the game, that "It is evident that the player has a 2/3 probability winning a round." I agree, it is evident, and I think even students can understand clearly and easily why this is the case. But then, why bother with the game?

Finally, I felt like the discussion of the three "loopholes" did not quite live up to what I was hoping for based on the beginning of the paper. Re: the communications loophole, the authors state that "Alice and Bob could win every round of the partners' version if they cheat by communicating with each other after seeing their question cards in phase 2." This is true (although I find it extremely confusing to describe this as a "loophole" -- surely "locality" is one of the central premises in the derivation of Bell's inequality.) But I was disappointed that the authors just *say* this but then all the subsequent discussion is about why superluminal communication is problematic vis a vis special relativity. (Incidentally, there are problems with this discussion. For one, there is really no meaningful notion of "nearly infinite speed". *Any* faster-than-light influence will appear to propagate with infinite speed in some inertial frame. Also, the whole argument is circular and unconvincing. If Bell's theorem and the associated experiments provide evidence that there is some nonlocality in nature -- and I think they do -- then we can hardly just assume any longer that special relativity, as ordinarily understood, is true. The same kind of theory that one might contemplate to reconcile Bell's result -- say, a theory in which the usual relativistic metric is supplemented with some additional structure such as a dynamically privileged spacetime foliation -- will automatically prevent the sorts of paradoxes discussed here. But my main point here isn't to complain about the content of this discussion of the relation between relativity and superluminal communication. Instead, I mean only to complain that this discussion is basically disconnected from the card game. It's the kind of thing one would find in any random website or popular book about Bell's theorem.)

I feel similarly about the second "loophole" discussed -- the "superdeterminism loophole". This is almost completely unrelated to the card game and is instead just a (not very good) discussion of the idea of superdeterminism. (The authors seem slightly confused about what the "super" in "superdeterminism" adds to mere "determinism". It does add something -- i.e., "superdeterminism" is *not* merely the idea that "nothing happens by chance". It is instead the idea that not only are the "randomly" or "freely" chosen measurement settings in the experiments determined, but that they are determined to be *correlated* in certain ways with the ("hidden variable") states of the photon pairs that are being tested. The idea is that there is a kind of cosmic conspiracy -- things that we have no reason to think should be correlated, and indeed things that experimentalists take explicit pains to ensure are not correlated, are nevertheless correlated in a conspiratorial way that, in effect, fools us into seeing violations of Bell's inequality. But again, my point here is not to complain about the content of the discussion, even though I find it somewhat wanting. Instead, I am just pointing out that it is somewhat disappointing that the discussion doesn't really relate to the card game at all.)

I liked the discussion of the 3rd loophole much more, since it is actually what I thought I was getting: a way of cheating at the game that helps me understand one of the Bell loopholes!

To summarize, what I thought I would find in the paper was a card game that closely paralleled the structure of the experiments testing Bell's inequality -- a game that would allow students to understand Bell's theorem itself by figuring out, after playing for a while, why they can never win... and which might also allow them to appreciate certain "loopholes" by finding creative ways to win the game (by stretching or violating the rules). I think I would really enjoy (and support the publication of) a paper that did that, and I enjoyed this paper to some extent because it did *some* of that. But at the end of the day I feel like it doesn't live up to that promise. It leaves too much of what's important about Bell's theorem (namely, understanding exactly what assumptions generate the inequality so one can understand what's at stake in the experiments) too obscure, the game is really only vaguely analogous to the relevant (local hidden variable) theories and experiments rather than perfectly reflecting them, and only one of the three loopholes really interacts significantly with the card game. If I was going to teach Bell's theorem and wanted to do so using a kind of "game", I would probably just keep it simple and do something that is more exactly parallel to the real experiments: make up 3 yes/no questions, have the students pair up and then answer one

randomly-selected question at soundproofed stations on opposite ends of the room. Challenge them to find a strategy that will allow them to reproduce the QM correlations and see what happens... (Let them figure out that they cannot do it unless they carefully arrange to refuse to answer under certain conditions, or they somehow rig the question selection so it is not random at all but correlated with their answer-strategies on a given run, or if they simply use their cell phones to text each other and update their strategies after seeing what questions they're asked.)

Anyway, although it definitely has some value, I don't think the paper will be helpful enough for most readers to warrant publication in AJP.

AJP Report 2: Reject publication

Review of AJP MS 29938.

I believe publication in AJP of this discussion of Bell's inequality must be refused. I base my judgement on the quoted paragraph copied immediately below. It is provided by the authors in the first section of the submitted article.

COPIED FROM THE SUBMISSION: "Although Bell's inequality is easy to prove[6], we avoid it here because the card game reverses roles regarding probability: Instead of the investigators attempting to ascertain the photons' so-called hidden variables, the players are acting as particles attempting to win the game by guessing the measurement angles. Another complication is that the original form of Bell's inequality does not adequately model the partners' version of the game because humans have the freedom to exhibit a behavior not observed by entangled particles (under ideal experimental conditions). In the partners' version of the card game, a penalty must be deducted from the partners' score whenever they are caught using a forbidden strategy (which we shall later call the β-strategy). The minimum required penalty is calculated in the appendix, but fortunately students need not master this calculation because the actual penalty should often be whatever it takes to encourage a strategy that mimics this aspect of entanglement (which we shall call the α-strategy.)"

The foregoing "explanation" of the article's card game contains its own admission of complications and makes no reasonably clear (to me) connection of the game to either the Bell inequality or to entanglement. This makes too great a demand on the desired reader - i.e., fails to answer the following required question positively:

Does it provide enough background information to be accessible to readers from other subdisciplines of physics?

The only likely exception is a reader who already understands both the Bell inequality and entanglement, and is mainly intrigued with the matter of "explaining" them to novices.

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