

Interdependent Human-Machine Teams: The Limits of Classical Team Science

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Abstract

We review the limits of classical team science from three perspectives, then the value of interdependence to a team and society. Afterwards, we include a review of our current research, our future research, and the generalizations that we have made in different contexts.

Introduction

We review the failure of the social science of teams from three perspectives, the value of interdependence as a resource to a team and its society, plus its limits.

The limits of classical team science. The limits of classical science of teams reviewed from three perspectives:

1. The National Academy of Sciences (p. 12, Endsley et al., 2022) reported that to unravel interdependent effects in a team may not be possible; i.e., the:

“performance of a team is not decomposable to, or an aggregation of, individual performances ...”

2. The lack of information to observers of an interaction may account for the validation crisis currently afflicting social science (Nosek, 2015), which led to a plan to overcome the problem, since retracted (Protzko et al., 2024). If confirmed, the lack of information in states of interdependence creates an intractable problem for the classical science of teams (Lawless & Moskowitz, 2024).

3. The data collected as information from the interactions of teams is independent and identically distributed (i.i.d.) data, which, by definition, precludes the recreation of a state of interdependence captured by i.i.d. data (Schölkopf et al., 2021).

The value of interdependence. Social science can recover with interdependence (Lewin, 1951). The very best teams act in states of maximum interdependence (Cummings, 2015). We have proposed a mathematics of state dependency (Davies, 2021) to model interdependence for human-human, human-AI, or human-machine teams (Lawless & Moskowitz, 2024). In our quantum-like model of interdependence for human-human, human-AI, and human-machine teams, we have applied Dirac’s (1935) quantum claims to teams that dependency represents a loss of degrees of freedom (*dof*); consequently, the loss of information among a team’s dependent parts is not supported by separability among the independent elements of models of teams (e.g., tensors in LLMs), but, instead, supported by orthogonal relations among complementary functions of dependent teammates (e.g., in a restaurant, the cook, waiter and clerk perform complementary functions).

Further, every human activity produces entropy. First, we hypothesized that a highly interdependent team (organization, system) in a state of dependency can trade the entropy generated by the team’s structure, producing least entropy production (LEP), few *dof*, and, thus virtually no internal information to independent observers; and, second, the result allows more of the expenditure of a team’s available energy to be directed at its productivity, producing maximum entropy (MEP), a tradeoff between a team’s structure and its performance. To counter the lack of information from the interaction, we have begun to use an approach similar to assembly theory (Sharma et al., 2023) that counts successful interactions and failures.

Current research. In our model, emotional distress increases entropy in a team’s structure, a trade-off diverting the available energy from a team’s maximum entropy production, reducing a team’s performance (Lawless et al., 2023). We proposed that, if generalized to a model of society with quantum-like coupled harmonic oscillators, it could

fulfill Lewin's vision proposed decades ago of an interdependent whole (Lewin, 1951), such as with a futuristic human-machine team, organization or system. There, under the uncertainty caused by free choice (e.g., the failure rate of corporate mergers is about 50%; in Christensen et al., 2011, exemplified by the recent failure of Walgreens' merger; in Lombardo et al. 2024), political compromise (Gutmann; Thompson, 2014) and innovation might be combined into an index as we have begun in our research that differentiates evolvable, autonomous, and observable self-organized assemblies (Sharma et al. 2023; e.g., Lawless & Moskowitz, 2025) of interdependent teams randomly seeking the positive emotion of "animal spirits" (Keynes, 1936).

Future research. For future research, we are currently exploring synchronous operations within a team, and the decision-making from competition between teams; tensors play a part in arranging structure (Kang et al., 2024). In this model, dependency in roles reduces information only as long as a firm's product transmissions are synchronized, otherwise, adaptation comes into play. Further, for animal spirits to arise, we argue that an "essential tension" (Kuhn, 1977) between teams leads randomly to a competition or debate between the best opponents possible.

Nash (1950) published the first solution to game theory, i.e., that countering each claim by an opponent produces an equilibrium. Our research (Lawless et al., 2023) reflects Nash's idea about the existence of an equilibrium between countering views. Given countering claims and given a team in a state of interdependence when the interactions among teammates remain coherent, and when two equally coherent teams compete or debate against each other, if every claim produces a counter claim, a Nash equilibrium has generated symmetry that lasts until external decisions (e.g., a vote) or internal synchronization failures break it.

Generalizations: Intermediate results indicate that vulnerability in a team under competition is identifiable; i.e., when a vulnerability is discovered, a team signals to opponents its vulnerability by increasing structural entropy production, reducing maximum entropy production, or both (Lawless et al., 2023; e.g., the collapse of Syria's government, in Coles et al., 2025). Generalized to spying, the best spies perform as well as any team member in that position; i.e., by keeping their contribution to structural entropy production low until a mission's completion (e.g., FBI, <https://www.fbi.gov/history/famous-cases/aldrich-ames>).

In future research, we first plan to work on synchrony and adaptivity among teammates, where additive interference implies a good fit, negative interference a poor fit, adaptivity a lessening of the latter. Then, generalizing, when servicing the trade-offs of the available energy to a team, we propose that claims from a team balanced by counterclaims made by a competing team are an example of the symmetry connected to the conservation of interdependence in a system or society, a measure of the freedom teams have to make decisions in their best interest, where every claim among free agents is countered, and where every decision by a team's

observers (e.g., juries, voters, judges) is an example of symmetry breaking.

We have also reviewed types of decision-making in relation to the information derived from symmetry breaking; e.g., consensus reports by the National Academy of Sciences (NAS) discuss the need to counter misinformation in science (p. 163, in Viswanath et al. 2024), techniques that could be viewed as censorship (p. 169, Viswanath et al. 2024), characterizing minority control (consensus-seeking) and lessening of information from breaking symmetry.

Using AI or machine technology to censor speech, however, not only ignores the value of educating the public about the politics of a scientific topic with symmetry breaking, but also does not allow interested other (younger) scientists to learn from the public challenges that produce the information generated by full-throated debates as part of symmetry breaking.

Similarly, concern has arisen about the threats by AI (Bengio et al., 2024). In contrast to the censorship of speech, we have found that the advantages afforded by interdependence, such as with public debates and majority rules, offer advantages that may counter the threats made to a free people, possibly including those that AI may pose to future generations of humans.

For example, we compared the completed closures of high-level radioactive waste tanks (HLW) at the Department of Energy's Savannah River Site driven by the majority rules of its Citizens Advisory Board (CAB) where eight (8) of its 51 HLW tanks have been closed since 1997, versus none of DOE Hanford's 177 HLW tanks guided by its CAB's use of consensus rules. Thus, we have concluded that while consensus decisions are preferred by central decision makers, they produce inferior results (Lawless et al., 2023).

We speculate that Gutmann and Thompson (2024) have the better idea when they state that compromise is necessary to govern; campaigning is necessary to remain in office. These incompatible ideas of Gutmann and Thompson help to explain why compromise is, and should be, difficult to achieve, but nonetheless produces superior results to the use of consensus rules (and to the logic of central decision making; Mann, 2018). The authors define compromise as: Mutual sacrifice amid willful opposition. We believe their ideas can be generalized to guide future human-machine teams with AI.

In future research, thus, we want to explore the symmetry not only within teams, but also between two competing teams, not only producing Nash (1950) equilibria, but also the consensus or majority-ruled decisions that follow for human-human and human-machine teams. We speculate that, facing uncertainty, only majority rules lead to symmetry breaking and the production of useful information for the winners, for the losers, and for the evolution of technology interdependently with society (de Leon et al., 2021).

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