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Interdependence Exposes the Limits of Classical Team Science

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ABSTRACT

We have been developing the mathematics of interdependence theory for human-human, human-machine, human-AI and machine-machine teams. We provide a brief update on our progress and the challenges we face. This includes a brief review of the limits of classical team science from three perspectives. Then we discuss the value of interdependence in a team. We also discuss our future plans, including the value of interdependence to a society and to the development of future technology to advance the science of human-machine teams.

Keywords: Interdependence, Symmetry, Human-machine-AI systems, System structures, System performance, Quantum-like mathematical model

INTRODUCTION

In this brief report, we review the failure of the social science of individuals and teams from three perspectives, then we review the value of interdependence as a resource to a team and society, and, finally, we review the limits of a mathematics of interdependence.

THE LIMITS OF CLASSICAL TEAM SCIENCE: A BRIEF REVIEW

The limits of classical science of teams and individuals reviewed from three perspectives:

1. The National Academy of Sciences (p. 12, Endsley et al., 2022) reported that to unravel the 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..."

   The Academy's claim implies the existence of a lack of information in the interaction, both to inside and to outside observers.
2. But the interaction may be generalized to individuals who are interacting with subjective memories of images and self-talk about themselves in different situations as they respond to questionnaires and surveys. The lack of information to individuals as observers of themselves may account for the validation crisis currently afflicting the social sciences (Nosek, 2015), which led to a plan developed by Nosek to overcome the

problem; however, this plan has since been retracted by the editors of *Nature* (Protzko et al., 2024). If our theories about interdependence are confirmed, there exists a lack of information in states of interdependence as claimed by the Academy that creates an intractable problem for the classical science of teams, but also to individuals (Lawless & Moskowitz, 2024). Moreover, the problems at the individual level may account for the paucity of mathematics applied to teams at the team, organization and system levels.

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). For example, and in support of our claim, a video, movie or television program is constructed and replayed with, for example, still-frames composed of i.i.d. data at a rate designed to give the illusion of reality, a rate for which the human-mind is unable to see or parse the individual frames (e.g., 24 frames per second is standard for movies, TV shows and streaming videos).

The Value of Interdependence

We believe that social science can recover with the mathematics of interdependence that we have developed (first proposed by 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 about symmetry in the interaction to teams that dependency represents a loss of degrees of freedom (*dof*). However, the loss of information among a team's dependent parts is not supported by separability among the independent elements for the models of teams (e.g., tensors in LLMs), but, instead, it is supported by orthogonal relations in reality among complementary functions of teammates (e.g., in a restaurant, the cook, waiter and clerk perform complementary functions, causing orthogonality of the information collected from among them to limit the information that each can share with each other).

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 with metrics similar to those used in assembly theory (Sharma et al., 2023) that counts the results of successful interactions, studies the complexities that arise, and analyzes the unexpected failures of interactions that may occur from time to time.

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, thereby 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 greater than the sum of its parts (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).

Challenges: It is a challenge to design and operate a system for a team when information about how the operation should be designed is missing. But we plan to push ahead with synchronization among teammates; and with errors with and without recovery, guided by self-organizational processes.

Future Research

For future research, we are currently exploring synchronous operations within a team, and the decision-making from competition between teams; for both of these, tensors play a part in arranging structure (Kang et al., 2024), but with hiding information simply by not generating it in the first place (no symmetry breaking). 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 two 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 a decision (e.g., a vote), the exposure of a vulnerability, or a synchronization failure breaks 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).

Challenges. 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 positive symmetry breaking.

We have also reviewed types of decision-making in relation to the information derived from adverse 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 used as censorship (p. 169, Viswanath et al., 2024), characterizing minority control (consensus-seeking) and the lessening of information from the lack of breaking symmetry.

Using AI or machine technology to censor speech, however, not only ignores the value of educating the public about a political or scientific topic with symmetry breaking, but also does not allow interested other (younger) scientists to learn from the public challenges that produce the positive information generated by full-throated debates as a critical element or a 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 the first two HLW tanks were closed in 1997, versus none of DOE Hanford's 177 HLW tanks guided by its CAB's use of consensus-seeking rules. Thus, we have concluded that while consensus decisions are preferred by central decision makers (CDM), separability among the different elements of the independent parts that figure into a CDM decision produces inferior results (Lawless et al., 2023).

We speculate that Gutmann and Thompson (2024) have this as their 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 collective decision making; in 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).

CONCLUSION

With research findings predicted by theory and by generalizations to new theory and new discoveries, our research has begun to pay off (for a preview of the mathematics, see Lawless et al., 2023; for an up to date review of some of the issues in play, see Lawless & Moskowitz, 2025). We have developed a quantum-like model of the interaction that accounts for the claim by the National Academy of Sciences (Endsley et al., 2022, p. 12). And we have concluded that the failure of social science itself is a key piece of evidence that our mathematical model has adopted about the cause of the lack of information in the interaction, also implicated in causing the failure of concepts for individuals measured by questionnaires, surveys and interviews. Our future research plans, once implemented, should provide additional evidence that we are on the right path to solve this important problem in order to advance the science of teams.

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REFERENCES

Bengio, Y. et al., Managing extreme AI risks amid rapid progress, Science Policy Forum, 384(6698): 842–845, 2024.

Christensen, C. M. and Alton, R. and Rising, C. and Waldeck, A. (2011), The Big Idea: The New M-and-A Playbook, Harvard Business Review, retrieved 10/27/2022 from https://hbr.org/2011/03/the-big-idea-the-new-ma-playbook.

Coles, I.; Malsin, J.; Al-Omar, A. (2025, 1/29), "What Syria's Secret Police Saw as the Regime Crumbled. Hastily abandoned documents show how the fallen government's vast intelligence apparatus struggled to comprehend and stop the rapid rebel advance," Wall Street Journal, retrieved 1/31/2025 link: cced594a.

Cummings, J. (2015). Team Science Successes and Challenges. National Science Foundation Sponsored Workshop on Fundamentals of Team Science and the Science of Team Science (June 2), Bethesda MD.

Dirac, P. A. M. (1935), The Principles of Quantum Mechanics, Oxford.

Davies, P. (2020), Does new physics lurk inside living matter? Physics Today, 73(8): 34–40 2020.

de Leon, M. S. P et al., (2021), The primitive brain of early homo, Science, 372, 165–171, doi: 10.1126/science.aaz0032.
de Tocqueville, A. (1835), Democracy in America, Volume 1.
Endsley et al., (2022), Human-AI Teaming, Nat. Acad. Sci., human-ai-teaming-state-of-the-art-and-research-needs.
Gutmann, A.; Thompson, D. F. (2014), The Spirit of Compromise, Princeton U. Press.
Kang et al., (2024), Measurements of the quantum geometric tensor in solids, arXiv, https://arxiv.org/pdf/2412.17809.
Keynes, J. M. (1936), The General Theory of Employment, Interest, and Money, London: Macmillan.
Kuhn, T., (1977), The essential tension, University of Chicago Press.
Lawless, W. F., Moskowitz, I. S.; Doctor, K. Z. (2023), A Quantum-like Model of Interdependence for Embodied Human--Machine Teams: Reviewing the Path to Autonomy Facing Complexity and Uncertainty, Entropy, 25, 1323. https://doi.org/10.3390/e25091323.
Lawless, W. F. and Moskowitz, I. S. (2024), Shannon Holes, Black Holes and Knowledge: Can a Machine become a "Self-Aware" Teammate?, Knowledge, 4: 331–357.
Lawless, W. F.; Moskowitz, I. S. (2025), Editorial: Special Issue. An entropy approach to interdependent human-machine teams}, Entropy.
Lewin, K. (1951), Field theory in social science. Selected theoretical papers. Darwin Cartwright (Ed.). New York: Harper & Brothers.
Lombardo et al., (2024), Walgreens is in Talks to Sell Itself, Wall Street J., 5d14c920.
Mann, R. P. (2018), Collective decision making by rational individuals, PNAS, 115(44): E10387-E10396; https://doi.org/10.1073/pnas.1811964115
Nash, J. F., Jr., (1950), Equilibrium points in n-person games, PNAS, 36 (1) 48–49.
Nosek, B., Estimating the reproducibility of psychological science, Science, https://www.science.org/doi/10.1126/science.aac4716, 2015. 8, 311–319, https://doi.org/10.1038/s41562-023-01749-9.
Schölkopf, B., Locatello, F., Bauer, S., Ke, N. R., Kalchbrenner, N., Goyal, A. & Bengio, Y. (2021), Towards Causal Representation Learning, arXiv, retrieved 7/6/2021 from https://arxiv.org/pdf/2102.11107.pdf.
Sharma, A.. et al., (2023), Assembly theory explains and quantifies selection and evolution. Nature 622, 321–328.
Viswanath et al., (2024), Editors. Understanding and Addressing Misinformatio About Science, National Academies of Sci., Engr., and Med., Washington, DC, doi.org/10.17226/27894.