frontiers | Frontiers in Physics

TYPE Original Research
PUBLISHED 12 January 2026
DOI 10.3389/fphy.2025.1715888

Toward tunable advantages of quantum-like teams: the physics of interdependent teams to "squeeze" uncertainty

William Lawless*

Departments of Mathematics and Social Psychology, Paine College, Augusta, GA, United States

Check for updates

OPEN ACCESS

EDITED BY
Daya Shankar Gupta,
South University, United States

REVIEWED BY
Francesco Scotognella,
Polytechnic University of Turin, Italy
Hossein Seilani,
Shahid Bahonar University of Kerman, Iran

*CORRESPONDENCE
William Lawless,
w.lawless@icloud.com

RECEIVED 06 October 2025
REVISED 24 November 2025
ACCEPTED 25 November 2025
PUBLISHED 12 January 2026

CITATION
Lawless W (2026) Toward tunable advantages of quantum-like teams: the physics of interdependent teams to "squeeze" uncertainty.
Front. Phys. 13:1715888.
doi: 10.3389/fphy.2025.1715888

Purpose: The aim of this study is to provide a mathematical physics of entropy to organize and operate teams, whether teams are composed of humans, human–machine–AI, or any combination thereof.
Method: We review three (3) case studies and two (2) field studies of interdependence. The first case study concerns 7-year-long oscillations between the U.S. Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC), which ended when South Carolina's Department of Health and Environmental Control (DHEC) requested the public's help. The second case study addresses randomness in business merger decisions. The third case study examines the validation crisis in social psychology, illustrated by the contrast between self-reports of suicidal ideation and suicide. The first field study explores the advantages under freedom versus command decision making (CDM), and the final field study addresses the physics of time-energy uncertainty.
Data: Guided by theory, the data provide information from the three case studies to test interdependence theory. For the two field studies, data are drawn from international data bases (e.g., the UN and the World Bank).
Results: Limited support is provided for classical coupled harmonic oscillators; in comparison, significant support is found for interdependent (quantum-like) teamwork.
Significance: This study reviews and replicates earlier studies and generalizes findings to energy–time uncertainty relationships.

KEYWORDS
quantum-likeness, quasi-time, human–machine–AI, gen-AI, coupled, squeezed, uncertainty

1 Introduction

In this article, we advance the mathematical physics of teams, despite their interdependence, described by the great Jones (p. 33, [1]) as producing "bewildering complexities." However, by turning away from interdependence, even though humans live their lives in interdependence, Jones missed how ordinary humans turn complexities into advantages. Self-organized teams exploit interdependence to amplify productivity. Compared to self-organized teams, such as SpaceX, bureaucratic teams or those organized from the top–down (CDM) increase uncertainty in the freedom of choice for a team's members, reducing ("squeezing") performance and reducing competitiveness and innovation (e.g., the turmoil in Boeing's structure squeezed its performance after it lost two commercial airliners and its space race to SpaceX; in [2]) (*see the definitions below)*.

In contrast to CDM, the freedom to choose how to organize and operate teams produces significant advantages compared to teams organized and operated under command decision making (CDM), advantages that offset those afforded by the adverse effects of CDM and, as we predict, those modeled by the tensor-moderated effects of Gen-AI [2]. There is more: although challenged by random effects (see [3]), we have uncovered interdependence as the hidden (i.e., embodied [4]) cause of social science's failed concepts and its inability to generalize, central to our advances in this article. Interdependence transmits social effects, whether generally additive and self-organized under freedom or destructive and repressive under authoritarianism (CDM); it transmits the signals exploited by self-organization and innovation; and its repression unleashes the restraints against corruption and espionage. However, without a mathematical physics of team organization and performance as a guiding objective, we see no way to mathematically justify or advance the physics of human–machine, human–AI, or machine–AI teams.

Despite our prior success, it is eventually necessary to model a connection between the neuroscience of individual minds and the actions of physical bodies. We begin with an overview of our findings and provide a mathematical physics model of a team and a quantum-like physics model of a team, followed by case studies, field data, and critiques. We conclude by outlining a path forward toward achieving a tunable model of mind–body–team interaction.

1.1 Interdependence model: definitions

1. Interdependence: two mutually dependent factors; two co-dependent individuals; members of a team (i.e., teammates); rivals; competitors; predator–prey mutuality; self-awareness.
2. CDM (command decision-making): top–down leadership that reduces interdependence.
3. SEP (structural entropy production): structural entropy is reduced by improving a team (e.g., good leadership and a good marriage) or increased by damaging the structure of a team (e.g., marital affairs or rejecting a corporate leader)
4. MEP (maximum entropy production): used to describe the amplified uncertainty in the co-dependent factor of a dependency pair.

1.2 Overview: a summary of our research

1.2.1 Classical models: summary

First, Gen-AI models use interaction information to produce knowledge [5]. Large databases are often curated to develop statistics (correlations, in [6]) in a confined domain for a narrow range of decisions with dedicated applications (e.g., driving a car, flying a drone, and providing cybersecurity). The big data, Gen-AI, or knowledge transmitted should be stable, valid, and generalizable from laboratories to applications in the field [7]. However, the information derived is usually collected from interaction products during training in closed systems; even if each step of an interaction is witnessed by real-time data collection systems, the associations produced are based on independent and identically distributed (i.i.d.) data that are then modeled by Gen-AI algorithms with separable elements (e.g., tensors; in [8]) and that do not generalize, if at all [9].

Second, as stated in 2022 by the National Academy of Sciences (NAS; in [7]), among individual members of a team, interaction products cannot be disentangled, similar to the inability to look inside quantum entanglement or superposition [10], suggesting hidden information that tensors cannot capture [8].

Third, however, correlations are not causality. By definition, i.i.d. data [11] cannot replicate the interdependent data generated and processed by interacting agents (viz., it is similar to the frames in a movie or video that produce an illusion of reality [9, 12]). The information derived from the i.i.d. data collected from interactions explains the replication crisis in the social sciences caused by the failure of cognitive concepts to be validated, creating the crisis—e.g., self-esteem [13], implicit racism [14], and honesty [15]. Moreover, our quantum-like theory of interdependence explains that the social data collected from self-organized roles are orthogonal, producing the lack of concept validation that has caused the cognitive crisis in classical team science [16]. Even so, we argue that the lack of generalizability by classical team science represents a greater failure than concept invalidity—it means that the science of teams lacks a solid foundation and functions more as an art than a rigorous science [17].

Fourth, *The New York Times* recently reported that Gen-AI appears to be missing a key ingredient [18],

> "LeCun, the chief scientist at Meta, …does not believe that A.G.I. is near …his research laboratory is looking at the neural networks that have entranced the tech industry …for the missing idea."

We have hypothesized in numerous articles that the missing ingredient in AI research today is a mathematical model of interdependence [17], which we reprise in this article and then extend to time–energy.

1.2.2 Summary of prior research

First, the primary benefit we have found for self-organized teams is that the least structural entropy production (*SEP*) generated by the structure of the best teams reflects an interdependent tradeoff between *SEP* and the maximum entropy production (*MEP*) for team productivity, a tradeoff exploited by the very best teams [17]. Furthermore, supporting the claim by the National Academy of Sciences [7], we have found that the structure of the best teams produces insufficient information when a team can direct the maximum amount of its free energy away from its structure (which can occur only if a team is at a low *SEP*) to increase productivity [19].

Second, when interdependent agents assume agency to self-organize, the advantages afforded counter the risks posed by authoritarians; specifically, to enable authoritarian rule, top–down CDM decision-makers suppress interdependence to govern using the i.i.d. data that they have made predominant, while interdependent agents, when free to self-organize around the hidden interdependent information they control, gain a significant advantage to counter authoritarians, gangs, kings, and any others who are not free [2]. Compared to central decision-making, or CDM, interdependent systems, such as free markets, produce more innovation, more productivity per employee, and less corruption than those under CDM (in [17]). The best interdependent teams outcompete weaker, more vulnerable teams [19]. Cassidy [20] pointedly adds that the free market

> "is soulless, exploitative, inequitable, unstable, and destructive, yet also all-conquering and overwhelming."

This "all-conquering and overwhelming" effect, we propose, includes Generative Artificial Intelligence (Gen-AI), which is thought to pose an existential threat to human existence [21]. However, it is discredited by providing users with misleading results (e.g., hallucinations; in [22]), which increase as situations become more complex [23], and has provided information that exploits the vulnerable [24]. A report by the MIT Media Lab indicates that the business value of Gen-AI may be an illusion for the vast majority of businesses (viz., 95% of corporations; in [25]). These problems ignore the concept of team agency (responsibility), one of the chief characteristics of interdependent teams. In comparison, we have written that interdependence is a synergistic resource of agency that generative AI, as presently constituted, cannot surpass [17].

Third, as an example of generalization [2], based on [26]'s time-symmetry conservation of energy, given least *SEP* and maximum *MEP* based on n teammates, the only way to increase *MEP* is to have $n+1$ members, as predicted by Cummings in 2015 [27], accounting for the motivation among organizations to merge as their problem size increases or its character changes. This success suggests a link to time blindness in teams, a similarity to quasi-time crystals [28], which we describe later. Overall, we conclude that the theoretical foundation for AI with agency integrated into a free market, free political economy, and open-ended debates that produce "all-conquering and overwhelming" advantages [20], which we replicate and extend here.

For future research in the field, we review and discuss a model of cognitive dissonance as an internal source of interference, along with tradeoffs in a team's structure–performance as an external source of interference. Combined in the minds of a team's leader and its members, a team with free choice and intelligence could couple the two sources of interference to make both tunable, a step toward modeling decision-making under uncertainty by human–machine–AI teams with the quantum-likeness of interdependence. This model assumes that the brain accesses static information as associations and embodied information as humans interdependently move about [4, 9]. If these two brain systems are orthogonal, it explains both the invalidity of cognitive concepts and the inability to observe team interactions [7].

1.2.3 General hypotheses

With details to follow, we propose three general hypotheses:

1. Social reality is made less confusing by impeding interdependence, the tool of CDM, but used at the cost of free choice, innovation, and quality of life.
2. Social reality is made more probabilistic by exploiting interdependence, the tool of democracies and republics, gaining free choice, innovation, and quality of life.
3. Interdependent teams can "squeeze" one dependent factor while amplifying uncertainty in its co-dependent factor.

1.2.4 Outline of article

Above, we listed our general hypotheses. In Section 2, we review classical and quantum-like models of teams. In Section 3, we review our specific hypotheses, case studies, and two field studies. In Section 4, we review the outcomes of the three case studies and analyses from our two field studies. In Section 5, we discuss the results and all of the hypotheses and their limitations; draw conclusions; and close with future plans.

2 Models of teams

2.1 A classical model of teams

Mathematically representing a team as a combination of simple harmonic oscillators, while retaining the metaphorical nature of the analogy, would involve creating a system of classical equations that captures the key aspects of team dynamics. This challenging task is simplified by our classical model of reality.

A classical approach is presented as follows.

1. We begin by defining the variables.
   $x_i(t)$: it represents the "state" or "output" of team member i at time t. This could be a scalar value representing their productivity, their contribution to the team goal (e.g., role), or another relevant metric.
   ω_i: it represents the "natural frequency" of team member i. This reflects its optimal work pace, its preferred type of task, or the frequency with which it contributes valuable insights.
   $F(t)$: it represents the external driving force applied by the team leader or project manager. This could be a function that describes the project timelines, milestones, financial rewards, or other external (motivational) factors that influence a team's behavior.
   k_{ij}: it represents the "coupling strength" between team members i and j. This reflects the degree to which their work influences each other. A positive value indicates constructive coupling (collaboration), while a negative value indicates destructive coupling (e.g., conflict, role interference, and belief disagreement).
   γ_i: it represents the "damping coefficient" for team member i. This reflects factors that can reduce its productivity, such as stress, burnout, or a lack of motivation.
2. Equations of motion.
   We can model the behavior of each team member as a damped, driven harmonic oscillator:

$$m_i \frac{d^2 x_i}{dt^2} + \gamma_i \frac{dx_i}{dt} + k_i x_i = F(t) + \sum_{j \neq i} k_{ij} \left(x_j - x_i\right), \quad (1)$$

where m_i represents the "inertia" of team member i (their physical resistance or mental reactance to changes in state). We set this to 1 for simplicity.

$k_i = m_i \omega_i^2$ is the spring constant for team member i, related to its natural frequency. Then, $\sum_{j \neq i} k_{ij}(x_j - x_i)$ represents the influence of other team members on team member i. If k_{ij} is positive and $x_j > x_i$, then team member j is positively influencing team member i and *vice versa*.

3. Interpretation.
   Left-hand side: The left-hand side of the equation describes the forces acting on team member i due to its own inertia, damping, and natural frequency.
   Right-hand side: The right-hand side describes the external driving forces and the influence of other team members on each other.
   Solving the equations: To analyze the behavior of the team, we need to solve this system of differential equations. This solution can be found analytically for simple cases (e.g., Hypothesis 1), but numerical methods are often required for more complex systems involving several team members.
4. Adding noise and stochasticity: To make the model more realistic, we could add noise terms to the equations to represent the unpredictable nature of human behavior:

$$m_i \frac{d^2 x_i}{dt^2} + \gamma_i \frac{dx_i}{dt} + k_i x_i = F(t) + \sum_{j \neq i} k_{ij} \left(x_j - x_i \right) + \eta_i(t), \tag{2}$$

where $\eta_i(t)$ is a random noise term with a certain distribution (e.g., Gaussian noise).

Challenges and limitations include the following.

Parameter estimation: Estimating the values of the parameters (e.g., k_{ij}, γ_i, and ω_i) would be very difficult in practice.
Simplification: The model is a gross simplification of the complex realities of team dynamics.
Interpretation: It can be difficult to interpret the results of the model and relate them to real-world team behavior.
Validation: Validating the model would be challenging.
Example (team of size 2): Let us consider a team of two members, Alice and Bob. The equations of motion would be

$$m_A \frac{d^2 x_A}{dt^2} + \gamma_A \frac{dx_A}{dt} + k_A x_A = F(t) + k_{AB}(x_B - x_A),$$
$$m_B \frac{d^2 x_B}{dt^2} + \gamma_B \frac{dx_B}{dt} + k_B x_B = F(t) + k_{BA}(x_A - x_B).$$

Here, k_{AB} represents the influence of Bob on Alice, and k_{BA} represents the influence of Alice on Bob.

5 Team performance metric: To assess the overall performance of the team, we define a metric such as

$$Power = P(t) = \sum_{i=1}^{N} x_i(t) = \sum \frac{teamwork}{\delta t}. \tag{3}$$

This equation crudely matches the findings of [27] and represents the linear sum of the contributions of all team members at time t, indicating greater power from decreased time. Users could then analyze the behavior of $P(t)$ to see how it is affected by the various parameters described in Equations 1, 2.

In Materials and Methods, we propose three case studies, the first a classical case and Hypothesis 1.

2.2 Quantum models of consciousness

2.2.1 Quantum basics

"The formalism of quantum theory in Hilbert space has been successfully applied to the modeling and explanation of several cognitive phenomena" (Aerts et al.; in [29]). These authors add that "'tension-reduction processes' can also describe situations where the conflicts between the competing answers cannot be fully resolved, so that the system is brought into another state of equilibrium," suggesting [30]'s countering strategy to reach an equilibrium between two opponents.

Recently, Busemeyer and Bruza used the quantum model to study games, claiming that their model addresses human behavior rather than cognition. However, in *Science*, [31] concluded that games did not yet match reality, especially when applied to multi-agent problems. In the review of their research published in the same issue of *Science*, Suleymanov concluded that "real-world, large-scale multi-agent problems …are characterized by imperfect information and thus are currently unsolvable[1]."

Inconclusive evidence exists that the brain produces consciousness by functioning as a quantum system ([32]). Regardless, we speculate that quantum agents may one day be in play, meaning that an exploration of the quantum-like effects of interdependence may continue to advance team science [17].

We agree with the review of quantum theory (QT) by [33]'s team's claim that "There is one obvious similarity between cognitive science and quantum physics: both deal with observations that are fundamentally probabilistic" (Hypothesis 2). QT accounts for the probability distributions of measurement results using two types of entities, called observables, A, and unobservable states, ψ, for which measurements may be taken, but where a measurement changes the state of the system and makes one of the hidden (dependent) factors observable (see Hypothesis 1).

In QT [34], all entities operate in an n-dimensional Hilbert space of vectors, with $|\psi>$, pronounced "ket psi," a state vector whose components are complex numbers forming a column vector (a complex number can be represented as $c = a + bi$ and its conjugate $c = a - bi$, with $i = \sqrt{-1}$). In contrast, $<\psi|$ is a complex row vector, pronounced "bra" psi (the two terms, "bra" and "ket" are derived from "bracket"). In QT, the inner product operation is a scalar; i.e., $<\psi|\phi> = \sum_{i=1}^{n} x_i y_i^*$, where the length of vector ψ is $\|\psi\| = \sqrt{<\psi|\psi>}$; its length is normalized so that when ψ represents the superposition $\psi = a|0> + b|1>$, $\sqrt{|a|^2 + |b|^2} = 1$. The square of the inner product is the probability of ψ to be observed in $|\phi>$. An observable, A, in QT is represented by an $n x n$ Hermitian matrix (or operator that produces an observable) with all of its diagonal entries being real numbers.

Any Hermitian (symmetric) matrix can be uniquely decomposed into eigenvalues, v_i, and eigenvectors, called projectors, P_i. A projector is an outer product (also known as a cross product) that projects one state onto another or onto a subspace—e.g., $||\psi> <\phi||$. Projectors are positive, semidefinite, and idempotent: $P^2 = P$; they are parallel when $P_i P_j = \delta_{i,j} = 1$ if $i = j$ or 0 when $i \neq j$ (i.e., orthogonal).

1 See the Research Highlight by Yury Suleymanov in the same issue of *Science*.

Projectors sum to the identity matrix; i.e., measuring A produces an observable as one of the eigenvalues, v_i. If a system is in a given state, the measurement is 1; if it is orthogonal, the result is 0. The sum of the eigenvalues squared equals 1. We explore orthogonality in Hypothesis 3.

If two operators, A and B, have the same eigenvalue, they commute

$$[A, B] = AB - BA = 0. \tag{4}$$

However, if they do not commute, it leads to the Heisenberg uncertainty principle at the quantum level. For the quantum-like level of teams, we set Planck's $\hbar$ to 1. We have proposed that quantum-like uncertainty relations apply to a team's structure, *SEP*, and to the uncertainty in the power of a team's productivity, *MEP*, in an interdependent uncertainty tradeoff [2].

$$\Delta SEP * \Delta MEP \geq 1. \tag{5}$$

This relationship (Hypothesis 4) indicates that as quantum-like uncertainty (entropy) in a team's structure is interdependently "squeezed" [35], the complementary uncertainty in its productivity increases correspondingly [36]. We retest the validity of this hypothesis with new data in field study 1.

Given the Hamilton, $H = T + V$, where T is the potential energy and V is the kinetic energy, with Schrödinger's equation $i\hbar \frac{d}{dt}|\psi_t = H|\psi_t$, but with i and $\hbar$ set to 1, we begin with two operators, $[H, t] = 1$, and we take the derivative of both sides:

$$[H, t]\,|\psi\rangle = (Ht - tH)\,|\psi\rangle, \tag{6}$$

$$d/dt\,(Ht - tH) = \frac{d}{dt}\,(t|\psi\rangle) - t\frac{d}{dt}|\psi\rangle, \tag{7}$$

$$= |\psi\rangle + t\frac{d}{dt}|\psi\rangle - t\frac{d}{dt}|\psi\rangle, \tag{8}$$

$$= |\psi\rangle = 1 * |\psi\rangle. \tag{9}$$

Thus, as the quantum-like uncertainty in the time, Δt, of a team's performance is squeezed [35], the team's uncertainty in energy, ΔE, increases correspondingly [36]. We test this generalization as Hypothesis 5 in the second study, or field study 2.

In Materials and Methods, we provide three case studies and two field studies, the latter to be examining quantum-like behavior in teams.

3 Materials and methods

Methods: Each specific hypothesis, guided by the physics of entropy generation in teams, details its method.

Data collection: Data from the case studies were derived from historic sources; data for the two field studies were drawn from international sources (e.g., the United Nations and the World Bank).

Statistical tests: For the two field studies, mathematical averages and correlations were calculated.

Software used: the software program used in this article is provided in the tables.

3.1 Case study 1: a classical study

In case study 1, we explore classical coupled harmonic oscillations without resistance (no audience) and with resistance (an audience).

3.1.1 Hypothesis 1

Without resistance, a debate produces social oscillations (e.g., a debate between two federal agencies, the U.S. Department of Energy, or DOE, and the U.S. Nuclear Regulatory Commission, or NRC) that continue without resolution. With resistance (an audience), a resolution may be achieved that advances an environmental cleanup.

3.2 Case study 2

We use this case study to explore random effects in business, where it is easily studied.

3.2.1 Hypothesis 3

Despite the use of talented and highly paid expertise, the outcome of mergers and de-mergers (spin-offs) is approximately 50% [37], indicating the random outcomes of interdependent organizations operating in a sea of interdependence, namely, a free market.

3.3 Case study 3: the crisis in cognitive science

The third case study explores the crisis currently existing in cognitive science. Thinking in reality does or does not interact interdependently with reality. We expect that when human thinking interacts with a game, it represents game-playing behavior that likely does not generalize outside the game [31]. For example, the Prisoner's Dilemma indicates the value of cooperation, but it neither tells us how to maximize cooperation nor that its greatest value occurs in competitive team situations, which [38] expressly rejected:

> "the pursuit of self-interest by each [individual player] leads to a poor outcome for all."

This outcome can be avoided, Axelrod argued, when sufficient punishment exists to discourage competition.

3.3.1 Hypothesis 3

When thinking is expressed in games or through self-reports, it reflects game-playing ability or self-reporting ability that does not generalize to other behaviors. Regarding cooperation, game-playing ability tells us nothing about cooperation in teams, which we have found is maximum in a team with minimum redundancy, making the roles orthogonal [39], and of greater importance, not requiring the punishment recommended by [38], but which is employed by CDM, namely, authoritarians, criminal gangs, kings, and whomever else seeks to suppress interdependence.

3.4 Field study 1: the advantages of organizing under freedom

Timeless arguments have been waged over the value of CDM versus bottom–up decision making that occurs in free countries (e.g., countering the claims of Marcuse, in [40]). In the past [2, 41], we used Kullback–Leibler diffusion against freedom for GDP/capita, the Corruption Perceptions Index, and the Environmental Protection Index (UN data, World Bank Data, Global Fire Power, etc.). In this study, we compute averages to replicate the earlier results. Our goal in this study is to further explore reasons supporting two news reports that the kill ratios in Ukraine's war with Russia and Israel's war with Iran provide an advantage of approximately 10:1 (cited in [2]). Our overall goal is to justify a mathematical physics that can produce generalizations from human teams to human–machine–AI teams [17].

3.4.1 Hypothesis 4

Using international tables (World Bank for GDP/capita and World Population for freedom score), we hypothesize that significant advantages accrue to self-organizations in freer countries than in CDM countries, independent of a nation's military prowess. However, in the tradeoff, by squeezing *SEP*, information on a team's structure is correspondingly reduced ("squeezed"), consequently losing information.

3.5 Field study 2: the timeliness of freely organized versus CDM teams

Flow: As uncertainty is reduced in the measurement of time processes in a team, we calculated correlations between factors derived from the information generated to the team about its time processes to determine whether that information is "lost" to the participants so engaged.

3.5.1 Hypothesis 5

One advantage of organization under self-organized businesses is their quickness compared to those businesses organized under CDM. However, this quickness creates a degree of energy intensity that leads to a condition known as "flow," where the uncertainty in "time" is squeezed.

4 Results

4.1 Case study 1

Oscillations. In Equation 1, by letting $m = m_0 e^{st}$, $m, k, = 1$, and $F, \eta = 0$ for an oscillating circuit ($Ls^2 + Rs + 1/C = 0$, with inductance, L = 1, capacitance, C = 1, and resistance, R = 0), we obtain $s = \pm i$. This represents the case of two speakers talking past each other without the resistance provided by audience feedback, as illustrated in Figure 1. The vertical y-axis is for imaginary values, with physical values displayed on the horizontal x-axis.

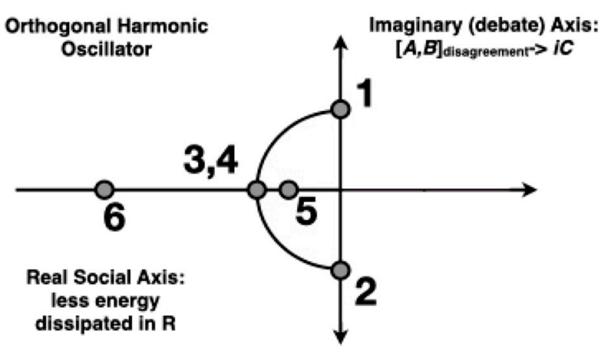

FIGURE 1
Debate model (from [42]). When two teams debate without resistance (i.e., no audience), we represent it by points 1 and 2 on the vertical y-axis, where $s = \pm i$; this "war of words" [43] creates an oscillation from strong beliefs held in imaginary space enacted publicly. However, as resistance increases (e.g., by the presence of an audience or a judge), a compromise decision can be represented by points 3 and 4 on the horizontal x-axis. Motivated by time limits and decided by observers, points 5 and 6 are the possible solutions that have overcome resistance, time, and energy (dissipation).

Figure 1 shows an example of an oscillation from the field and the energy wasted over time. In this case study, monthly debates occurred over approximately 7 years at the Department of Energy's (DOE) Savannah River Site (SRS) in Aiken, SC. In this case, DOE-SRS had successfully closed two of its highly radioactive high-level waste (HLW) tanks in 1997, the first two regulated closures in the United States and, possibly, the world [44].[2]

However, before DOE could close its next two HLW tanks, DOE was sued and lost, preventing it from closing more tanks. To allow DOE to continue to close more HLW tanks, the National Defense Authorization Act of 2005 was passed, which allowed DOE's HLW tank closures to resume[3]. However, it also entailed a compromise. The new law stated that the U.S. Nuclear Regulatory Commission (NRC) must provide oversight of DOE's decisions for additional HLW tank closures. As a consequence, unplanned, no matter the closure plan proposed by DOE, NRC requested changes, producing the oscillation between the two federal agencies, DOE and NRC, that lasted for longer than six (6) years.

The delay caused the State of South Carolina's Department of Health and Environmental Control (DHEC)[4] to become alarmed that DOE might miss its legally mandated deadline to close its next two HLW tanks (viz., HLW tanks 18 and 19). At a meeting of DOE's SRS Citizens Advisory Board (SRS-CAB), which included representatives from DOE, NRC, and DHEC, SRS-CAB proposed a recommendation urging DOE and NRC to resolve their technical differences[5]. The recommendation was approved by the full SRS-CAB, with the citizens demanding that DOE and NRC settle

2 Drafted by the author as a member of the SRS-CAB in 1997.

3 https://www.govinfo.gov/content/pkg/PLAW-108publ375/pdf/PLAW-108publ375.pdf

4 The South Carolina Department of Health and Environmental Control (DHEC) is the State agency responsible for public health and environment in South Carolina; see https://scdhec.gov.

5 Requested by DHEC, the recommendation was drafted by the author, who was previously a member of the SRS-CAB, but a former member at that time.

their differences and immediately restart tank closures, which subsequently happened[6]. Paraphrasing a member of DOE's staff, it was the fastest decision ever adopted by the citizens, accepted by DOE-SRS, and enacted by DOE-HQ that he had witnessed in his career.

4.2 Case study 2

4.2.1 Mergers and breakups

Mergers occur for defensive reasons, to reduce costs in a consolidating market and, among other reasons, to become more competitive and gain market power [45]. Market power is the ability to control prices [46]:

> "on average, the firms studied increased their market power as a result of mergers …"

In support of our hypothesis, despite large budgets, sophisticated studies, and experienced personnel, mergers have no better outcomes than a failure rate of approximately 50% [37], representing random results (see [47] for the value of uncertainty in human decisions and [3]), suggesting not only probability but also unobservable effects, which agrees with the National Academy of Sciences (p. 12 in [7]; see also [48]) that the

> "performance of a team is not decomposable to, or an aggregation of, individual performances."

In contrast, poorly performing mergers (including marriages; [49]) lead to spin-offs (or divorces) as do major businesses and banks that have lost their way. For example, [50] stated that to

> "…help pull Citi out of a 15-year slump …Citigroup is nearing an important milestone in efforts to spin off its Mexican consumer bank, an important part of …[its] turnaround strategy.

Case study 2 provides support for random outcomes in the interaction.

4.3 Case study 3

4.3.1 Self-reports

In 1995, the American Psychological Association (APA) hailed self-esteem as the gold standard of wellbeing: "self-esteem …is generally considered to be a highly favorable personal attribute" [51]. We requested from the search engine Safari an AI overview of self-esteem and received this response (*abridged*):

> *High self-esteem is linked to a reduced risk of anxiety, depression, and other mental health challenges… .
>
> *Greater Success: Research suggests that high self-esteem can contribute to better performance in school, work, and other life domains.

Based on this AI overview and the American Psychological Association's designation of self-esteem as its gold standard, a high probability of linking self-reported self-esteem and *physical* success with academics or work should occur—i.e., treating self-esteem and academics or work as vectors, at a maximum, $| < \psi|\phi > |^2 = 1$:

$$| < Self - Esteem|Academics|^2 \le 1; | < Self - Esteem|Work|^2 \le 1. \tag{10}$$

However, the evidence indicates that Equation 10 holds only when correlating with other self-reported cognitive beliefs, but not actual academic or actual work performances, leading to Nosek's declaration in 2015 of a crisis in cognitive science [16]. [13] struck the first blow against the cognitive model in 2005 by finding that self-esteem was not related to academic or work performance, thereby beginning the "crisis." This was followed by several other concepts also be found invalid, such as implicit racism [14], Baumeister's own theory of "ego-depletion" in 2016 [52], and "honesty" in 2021 [15]. Doubts regarding the priming research of Bargh were singled out by Kahneman in his book *Thinking, Fast and Slow* [53].[7] Nosek's team later proposed a solution to overcome the crisis, but it failed, leading to its retraction by *Nature* in 2024 (Protzko et al., in [54]).

Instead of finding that the self-reported cognitive model is congruent with reality, it has been found to be unrelated, such that the vectors representing self-esteem, actual academics, or actual work, imply orthogonal relationships:

$$| < Self - Esteem|Academics|^2 \approx 0; | < Self - Esteem|Work\ success > |^2 \approx 0. \tag{11}$$

In retrospect, we find that Equation 10 supports the theory of cognitive dissonance [55], which causes distress, anxiety, or destructive interference when individuals become aware that their thoughts or actions are in conflict with one another or reality, and that self-reports are behaviors, supporting Equation 10 but not Equation 11. Thus, cognitive beliefs correspond to one another but apparently not to the behavior claimed, nor do they generalize to other behaviors. However, generalization to the theory of effort justification supports Equation 11 and a path out of the dilemma that links cognition to observable behavior in the physical world [56, 57] (see conclusion).

This alerts us to the possibility of problems with other self-reports of behavior. Take, for example, suicidal ideation and physically observable suicide. From recent research on suicide [58],

> "self-esteem was shown to have a unique relationship with suicidal ideation"

However, from an earlier researcher on self-esteem and suicide [59],

6 https://cab.srs.gov/library/recommendations; see recommendation 284.pdf.

7 Chapter 4, (Replicating) Implicit Priming, https://replicationindex.com/2020/12/30/a-meta-scientific-perspective-on-thinking-fast-and-slow/

> "previous suicide attempts strongly predict future attempts …some ideators …experience persistent ideation [and] researchers instead often study suicidal thoughts and/or behaviors as proxies for suicide."

This quote may or may not represent Equation 11. However, the same lead author also concluded that there is a poor correlation between suicidal ideation and attempts to commit suicide [60]:

> "A World Health Organization study found that approximately two-thirds of individuals with suicidal ideation never make a suicide attempt, and a population-based study found that only 7% of individuals with suicidal ideation attempted suicide during the subsequent two years."

To put matters into perspective, as noted in the Proceedings of the National Academy of Sciences (p. 35, in [61]),

> "While approximately 46,000 suicides occurred in 2021, millions more experienced serious suicide ideation or attempts, representing critical intervention opportunities to prevent suicides … "

4.4 Field study 1 advantages: freedom versus CDM

In Table 1, we collected raw data on GDP/capita[8], data on freedom[9], and data on military power[10]. From the raw data, we calculated averages.

The results of field study 1 show significant advantages for nations with the freedom to permit self-organization, but no advantage for CDM or for military strength.

4.5 Time and energy: correlation matrix

To obtain the correlations shown in Table 2, we focused on public sources of data available online. We considered the world's 10 largest economies[11] primarily. In the table, we contrasted Gross Domestic Product *per capita* (GDP/capita)[12]; Innovation Index[13]; Corruption Perceptions Index (CPI)[14]; freedom[15]; energy used, in million tons oil equivalent (mtoe), divided by the population from the CIA World Factbook[16]; and time, in days, to start a business, with the data provided by the World Bank[17].

In Table 2, the column labels are GDP/capita, innovation index, low CPI, freedom, energy used *per capita* (E/mtoe/capita), and time (in days to start a business).

From Table 2, we report here only the correlations for *time*, *energy*, and *innovation*. To address Hypothesis 5, we included energy and the average time, in days, required to start a new business, using the World Bank's former measure of business competitiveness (the World Bank discontinued data collection for this time measure in 2021; see the link above).

4.5.1 Time

The average time it took to start a business in a nation was inversely related to that nation's GDP/capita $(r = -.75, p < .05)$; significantly and inversely related to a nations ability to innovate $(r = -.66, p < .05)$; significantly and inversely related to the perception of corruption in a nation $(r = -.71, p < .05)$; favorably and inversely, but not significantly, related to freedom in a country $(r = -.23, p > .05)$; and strongly, but not significantly, related to the energy consumed *per capita* in a nation $(r = .53, p > .05)$.

4.5.2 Energy

For energy, we found that it was significantly related to GDP/capita $(r = .81, p < .01)$; significantly related to innovation $(r = .70, p < .05)$; strongly, but not significantly, related to the Corruption Perceptions Index $(r = 39, p > .05)$; significantly related to freedom $(r = .73, p < .05)$; and strongly, but not significantly, related to the average time required to start a business in a country $(r = -.53, p > .05)$.

4.5.3 Innovation

We found innovation to be significantly related to GDP/capita $(r = .72, p < .05)$; related to low CPI (but not significantly) $(r = .40, p > .05)$; positively, but barely, related to freedom $(r = .15, p > .05)$; significantly related to energy/capita $(r = .70, p < .05)$; and significantly related to the average time required to start a new business in a nation, an indication of competitiveness $(r = -.66, p < .05)$.

5 Discussion

5.1 Discussion of the three general hypotheses

Based on the results of the five specific hypotheses, the following three general hypotheses are supported.

---

8 gdp *per capita* at https://data.worldbank.org/country

9 https://worldpopulationreview.com/country-rankings/freedom-index-by-country

10 https://www.globalfirepower.com/country-military-strength-detail.php?country

11 Russia, USA, China, UK, Japan, India, Brazil, Canada, Europe (estimated), and Mexico.

12 https://www.forbesindia.com/article/explainers/top-10-largest-economies-in-the-world

13 https://www.theglobaleconomy.com/rankings/gii)

14 https://www.transparency.org/en/cpi/2022

15 https://freedomhouse.org/countries/freedom-world/scores

16 https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html and https://www.cia.gov/the-world-factbook/

17 World Bank's ranking for a nation's competitiveness (https://data.worldbank.org/indicator/IC.REG.DURS?most recent value desc = true; the Doing Business Report was discontinued in 2021; see https://www.worldbank.org/en/news/statement/2021/09/16/world-bank-group-to-discontinue-doing-business-report

TABLE 1 Advantages of the freedom to self-organize.

Country	GDP/c, k	Advantage	Freedom	Advantage	Military**	Advantage
Iran	5.7	-	11	-	135	-
Israel	54.1	9.49	77	6.64	117	1.16
China	13.3	-	9	-	35	3.37
Taiwan	38	2.86	94	10.4	126	-
N. Korea	1.26	-	3	-	265	-
S. Korea	33.1	20.7	81	27	73	3.63
Russia	14.9	2.76	12	-	34	4.85
Ukraine	5.4	-	51	4.3	165	-
Ave. of advantages***		7.57		12.08		−0.85

** is an inverted scale (i.e., a higher score is a weaker military);
*** A positive value occurs iff (if and only if) a freedom advantage was obtained.

TABLE 2 Time-energy explorations.

Correlations to explore energy–time uncertainty relations					
GDP/cap	Innov.	CPI	Freedom	E (mtoe/cap)	Bus. time
1					
0.72*	1				
0.03	0.40	1			
0.59	0.15	0.73*	1		
0.81**	0.70*	0.39	0.73*	1	
−0.75*	−0.66*	−0.71*	−0.23	−0.53	1

*For n = 10, the correlation is significant at p < .05 (means less than 5% error).
**For n = 10, the correlation is significant at p < .01 (means less than 1% error).

1. CDM represses interdependence (e.g., free choice), increasing the need to steal technology, innovations, and ideas, as illustrated by Russia [62] and China [63].
2. Mergers [37], acquisitions, and spin-offs, coupled with marriages and divorces [49], illustrate well the random effects that occur in social life, obscured by the repression of data and the hidden nature of the interaction.
3. Interdependence in a team is needed to explore reality and uncertainty as a team is constructed as a business process or as a marriage is worked out to increase performance, innovation, and quality of life.

5.2 Discussion of the five hypotheses

1. Case study 1: Oscillations during a debate help an audience process the uncertainty entailed. If a belief, idea, or thought is strictly cognitive and not expressed, we represent it by $|\psi>$, which must be measured to be of use, as in a debate. We have found that the value of debate leads to the best decision [64], whereas consensus-seeking blocks action [44]. The key to developing intelligent machines and systems interdependent with humans is to interlink interdependence with reality—e.g., linking debate to the decision that led to the struggle to clean up DOE’s mismanagement of military nuclear waste [44].
2. Case study 2. The generally poor outcome for mergers [37] provides support for the claim by [33] that random outcomes occur in social processes. Based on the two examples given in case study 2, one of a merger and another of a spin-off, we conclude that a firm gaining power from a merger is an example of a whole greater than the sum of its parts; in contrast, a spin-off is an example of a whole less than the sum of its parts. Assume that an owner or an enterprise is an operator (i.e., $P = P_0 = P^2$). According to [65], the invisible hand pushes an owner to increase the productivity of a business with a division of labor. Smith used the example of the pin factory. One worker

could produce one pin a day, meaning that 10 workers would have a degree of freedom of 8, but 10 specialized workers working together could produce 48,000 pins per day. They have to work together, which affects their degrees of freedom; for the best team, a well-run team's structural entropy, in the limit, becomes

$$S_{team} = \lim_{dof \to 1} log(dof) = 0. \quad (12)$$

3. Case study 3: In an experiment conducted by USAF educators, the education of USAF fighter pilots [66] did not match reality; however, the results of education associated with patents in Middle East and North African (MENA) countries supported the value of education [19], indicating an orthogonality between physical skills and intellectual concepts. Recently [2], we discussed the limits of classical team science, based on the failure of cognitive concepts to be validated, which caused the crisis in cognitive science [16]. Now, however, we are coming to believe that the validity crisis between cognitive concepts and actual behaviors is evidence in support of orthogonality [17], addressed in the conclusion.
4. Field study 1: A highly productive team, based on an appropriate division of labor [65] and coupled interdependently, amplifies the productivity of its individuals as its structural entropy is squeezed [2]. Field study 1 supports the hypothesis that advantages accrue to freer countries compared to authoritarian countries (e.g., as an example of the effect of authoritarianism [67]):

> "The government of the People's Republic of China (PRC), guided by a totalitarian ideology under the absolute rule of the Chinese Communist Party (CCP), deprives citizens of their rights on a sweeping scale and systematically curtails freedoms as a way to retain power."

Thus, authoritarianism impedes freely organized social processes by squeezing the constructive and amplifying the destructive effects of interdependence. In field study 1, we have replicated our previous two studies [2, 41] and Bohr's correspondence principle with squeezed uncertainty [35], but by allowing a team to freely use its intelligence to choose the best available direction forward.

5. Field study 2: Equation 3 crudely matches the findings of [27] and represents the linear sum of the contributions of all team members at time t, where the results in Table 2 indicate greater power, $P(t)$, from decreased time. Moreover, field study 2 aligns with Cohen's (p. 45, in [68]) findings on signal detection for transformations between Fourier pairs: a "narrow waveform yields a wide spectrum, and a wide waveform yields a narrow spectrum; both the time waveform and frequency spectrum cannot be made arbitrarily small simultaneously."

   The success of Field Study 2 suggests a link to time blindness in teams, analogous to quasi-time crystals: team flow occurs when a group engages deeply in tasks to achieve a goal, commonly observed in performance and sports. …"[to provide for] experiences during which individuals are fully involved in the present moment" [69].

5.3 Criticisms of the classical model

Although limited, the classical model in Figure 1 works well, but it provides no insight into intelligence in interdependent situations, such as strategy, vulnerability, and team member substitutions.

Physical interdependence has begun to be applied to the production of new laser materials [70]; to impeding drunk driving [71]; to improve the safety of trains [72]; and, for some years now, to the recovery of F-16 fighter pilots who have lost consciousness from excessive G-forces [73]. In these cases, interdependence does not include a human's or a team's embodied intelligence arising from a combination of mental and physical reactance (i.e., interference). Interdependence is partial because these systems are mindless; while they may react physically like living organisms, they cannot be queried about what they are thinking, planning, or believing at any moment in time. AI-enabled collaborative combat aircraft (CCA), combined with fifth-generation fighters and bombers, are planned as part of its Next-Generation Air Defense systems to counter China [74]. CCAs are intended to have some level of autonomy along with humans, making it critical to develop robust interfaces and efficient command and control systems for complex operational missions.

A further problem is that the science of teams is contingent on AI to build trust and cooperation to reduce risks to users and society, but it currently has no mathematical algorithms to direct or optimize the behavior or cognition of AI, machines, or robots ([7, 9, 75, 76]).

Although it is possible to create a mathematical representation of a team as a combination of harmonic oscillators, the resulting model would be a highly simplified and abstract representation of reality. The model could be useful for exploring some key concepts of team dynamics, as we have done with case study 1, including interdependence, communication, and resonance, but it is important to be aware of its limitations, principally that its elements are separable (i.e., tensors; in [8]).

5.4 Criticisms of the basic quantum model

Based on our results, cognition and behavior are not always linked. The results in this article suggest that the link, when it occurs, is caused by interference such that one belief is interdependent with another; if destructive, it fails to become aligned by generating cognitive dissonance [55], but if constructive, it becomes additive. This may explain why babies struggle to find balance by minimizing the interference arising in their brains with the interference they are generating as they step forward [77]; it explains the destructive interference that addicts may perceive when attempting to recover but subsequently backslide [78]; and it explains why humans are poor at multitasking [79], whereas multitasking is the function of teams [19].

5.5 Summary of classical and basic quantum models

In support of the quantum-like model of interdependence, first, the results of interactions and choices in the marketplace are probabilistic—random on average [37] —and indicate that interdependence among free agents is a synergistic resource (e.g., compared to central decision-making, or CDM, it produces more innovation, more productivity per employee, and less corruption than CDM [2]).

5.6 Conclusion

Today, models of teams are classical, but quantum models of decision-making exist, making it conceivable that one day a quantum agent may arise, with the role of a quantum agent as a team member becoming a research topic. In our research, compared to top–down CDM teams, we have established the mathematical physics of interdependence as quantum-like in nature, providing a comparative advantage for freely organized and operated teams and serving as a corrective to the potential disadvantages of Gen-AI. To reach our goal of advancing the physics of teams, in this article, we began with a classical approach to coupled classical harmonic oscillators as a model of a team but with uncertainty that cannot be "squeezed"; then we introduced the quantum-like model that can be "squeezed" (i.e., amplified); we applied and critiqued both; and we discussed coupled quantum harmonic oscillators as a tunable control of a team. Our overall goal will be satisfied when we provide mathematical physics sufficient for the development, operation, and performance of any combination of human–machine–AI-robot teams, which includes a consideration of Gen-AI models. Gen-AI offers benefits (e.g., insights from data analysis) and impediments (e.g., an existential threat). In contrast, our quantum-like model and results indicate that interdependence is a resource (agency and responsibility) that neither CDM nor generative AI, as currently constituted, can surpass.

The processes in the brain that lead to a spoken, written, or suggested comment, preference, or decision cannot be observed; they remain implicit and inaccessible. Individual self-reports, statements, or actions can be observed, but not the dissonance, dissembling, or implicitness behind them. This point aligns with the National Academy of Sciences (p. 12, in [7]; see also [48]), which states that observers cannot disaggregate the causal contributions of individual team members.

Can a robot dream, enjoy the movies, and debate? Like young basketball players watching their star players to simulate their stylistic maneuvers on the basketball court, from MIT News [80], Gen-AI robots can perform by observing simulations of real-world data:

> "LucidSim combines physics simulation with generative AI models, addressing one of the most persistent challenges in robotics: transferring skills learned in simulation to the real world."

Movies are being used to train robots on physical maneuvers. However, this process of using movies has been challenged by [9] as unrealistic. The line of reasoning based on case study 3's results suggests that simulations of reality that more closely align with a behavior needing to be trained in reality improve that skill; for example, commercial pilot Instrument Flight Rules (IFR) training in a simulator improves real-world skill of flying under instrument-controlled conditions (IFR; in [81]), whereas combat simulation is less effective [82].

We agree with another claim by the National Academy of Science [83] in its review of team science, "the science of team science is not yet well developed" (p. 2); thus, generalizability remains poor. In addition, "high task interdependence often requires close coordination and cooperation among team members to achieve shared objectives" (p. 24). Furthermore, team tasks demand a team size that matches the interdependencies of the task (p. 29). While we agree with the National Academy of Sciences regarding generalization to other human teams, the absence of specified equations means that generalization to AI–machine–human teams is not only impossible, but also how to maximize cooperation cannot be specified even for human teams. In contrast, based on the production of observable amounts of entropy, we have found that maximum cooperation is achievable only for orthogonal roles [2]—e.g., cook–waiter in a restaurant or husband–wife in a marriage. Moreover, while we agree with the National Academy of Sciences regarding team size, only we can specify this result mathematically for humans and machines, namely, when team structure entropy production, *SEP*, remains at a minimum.

Furthermore, neither the classical science of teams nor the quantum consciousness and quantum behavior models have been able to generalize to new predictions in the field; however, our quantum-like model has generalized, including in this study to energy–time relationships, and in our earlier studies to the value of boundaries (which reduce the interference from sources external to a team [39]); vulnerability in a team (vulnerability increases structural entropy, *SEP*; in [19]); and the idea that an individual's sense of a unified reality is an illusion [12], as is the magic of cinema (i.e., "mise en scène," in [84]; also [19]). Together, these suggest a link among interference patterns, dreams, and holograms [85].

The difficulties with robots are not surprising despite the success of Gen-AI [9]. Human language accounts for a small amount of behavior (communication is 55% nonverbal, 38% vocal, and 7% words only (in [86])), primarily for communication [87], and words are not critical to the process of thinking [88], yet the big-data approach begun by Gen-AI (including LLMs), tensors, and machine learning (ML) may one day provide a path to solving other, more difficult problems, like the interaction.

The *Wall Street Journal* recently reported two contradictory articles that robots make lousy teammates, a problem China aims to be the first to solve [89], and that companies are rushing to teach AI agents how to collaborate. Underlying these articles is the suggestion that civilization is rushing helter–skelter into developing dual-use technology for competition and war with minimal human interaction; e.g., "goals with memory, planning, and autonomy …scientific discovery, customer service, healthcare education, or personalized support …automate routine tasks, analyze data for insights, and optimize processes" [90].

> "The vast 'brains' of artificial intelligence models can memorize endless lists of rules. That is useful, but not how humans solve problems" [91].

Finally, further theoretical, mathematical, and engineering progress is needed for teams in the future [9]. However, at this time, we observe the following: cognitive dissonance is a cognitive phenomenon. Effort justification [92] is the missing key to linking cognition interdependently to physical reality, but only with difficulty or hard work, as exemplified by Einstein's struggle to generalize his special theory of relativity to include acceleration and gravity [41].

5.7 Future plans: tunable quantum-like system flow

For future research on the mathematical physics of partially observable sources harboring the information dualities developed by a mutual dependency, if we model cognitive dissonance as a source of interference and a team's structure–performance as an external source of interference, then a team leader, guided by its intelligence, couples the two sources of interference to make both tunable, a step toward modeling decision-making and debate by human–machine–AI teams in the field with the mathematical quantum-likeness of interdependence.

For debate, we speculate the following. As a debate unfolds, the context being constructed provides insights to participants [93] on whether to adopt, modify, or reject a belief or action (e.g., Justice Ginsburg [94] believed that the judicial review of lower court rulings provided her an "informed assessment of competing interests," p. 3). It could be a function of ideology, education, charisma, etc., all with unique signatures of entropy production, according to whether they characterize the weaknesses or strengths of a debate as the context is formed. As described in case study 1, under majority rule, boundaries form around two choices, creating a strengthening or weakening field surrounding the arguments of one or the other debater [95]. Under the consensus-seeking rule, the boundaries can encapsulate up to N participants, therewith stifling or precluding action; e.g., guided by the majority rule of its DOE citizens advisory board (CAB), compare DOE's Savannah River Site, which has been closing its extremely radioactive HLW tanks since 1997, whereas under the guidance of the consensus-seeking CAB at DOE Hanford, there have been no closures yet of the HLW tanks at DOE's Hanford site [44]; in support, from the European Union's White Paper from 2001 [96],

> "The requirement for consensus in the European Council often holds policy-making hostage to national interests in areas that the Council could and should decide by a qualified majority" (p. 29).

When the two sides of an argument are equally balanced, the likelihood of a compromise increases [64]. However, when free choice is in play, the decision is often for action to complete or accelerate the action—e.g., the radioactive waste cleanup of DOE's mismanagement [41].

Generally, the end result of interference can be tracked with i.i.d. data and modeled by tensors; the data can be hidden, entangled by interdependence, until a measurement is performed. If [97]'s "single perceptual image" is constructed by a collapse, it may be that interdependence from the brain's two-halves constructs the illusion of reality [12]; in turn, if that construction is interdependently coupled with a free society to form a technology–culture interaction, then it should become a driver of evolution [98], innovation, and progress [99]. Data remain a problem; prediction continues to be poor (e.g., the Presidential and Brexit misses of Tetlock's superforecasters in 2016 [100]), but measurement is advancing. As teams persist, Hamiltonian-type learning [101] is expected to advance to "snoop" on real teams (e.g., spies, espionage, and scientists).

If we modify [53]'s model by assuming that the brain accesses two types of information, one static in nature to permit associations and another embodied interdependence as humans think and move physically and socially, then an orthogonality between these two brain-mind networks accounts for the invalidity of cognitive concepts—the ability to move, think, socialize and the inability to fully capture all aspects of an interaction by observation. For example, a human can safely park a car, dance with a partner, or land a jet at night on an aircraft carrier, yet be unable to articulate exactly how. This is why research on surreptitious (covert) channels remains important [41], and why Simon's [102] theory of behavior relied on the uncertainty cloaked behind bounded rationality. Instead, for teams, reforming orthogonality, as Einstein did, requires sufficient struggle to forge a team into a unit.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

WL: Writing – original draft, Writing – review and editing, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization.

Funding

The authors declare that no financial support was received for the research and/or publication of this article.

Acknowledgements

The authors acknowledge the contributions of Ira Moskowitz, Mathematician, Information Technology Division, Naval Research Laboratory, Washington, DC, to this manuscript. They also thank both Ira and Ranjeev Mittu, NRL, where parts of this manuscript were written during the summer of 2025.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

References

1. Jones EE. Major developments in five decades of social psychology. In: DT Gilbert, ST Fiske, G Lindzey, editors. *The handbook of social psychology*, 1. McGraw-Hill (1998). p. 3–57.

2. Lawless WF. The symmetry of interdependence in human - ai teams and the limits of classical team science. *AppliedMath* (2025) 5:114. doi:10.3390/appliedmath5030114

3. Prigogine I. *The end of certainty*. Simon and Schuster (1997).

4. Shapiro L, Spaulding S. Embodied cognition. In: EN Zalta, U Nodelman, editors. *The stanford encyclopedia of philosophy* (2025). Available online at: https://plato.stanford.edu/archives/sum2025/entries/embodied-cognition/.

5. Lawless WF, Moskowitz IS. Human–machine teams: advantages afforded by the quantum-likeness of interdependence. In: WF Lawless, R Mittu, DA Sofge, M Brambilla, editors. *Bidirectionality in Human-AI collaborative systems, Chapter 18*. Elsevier (2025). p. 451–73. doi:10.1016/b978-0-44-340553-2.00024-1

6. Hill K. *Chatbots hallucinate. They can make people do it, too*. New York, NY: New York Times (2025). Available online at: https://www.nytimes.com/2025/06/13/technology/chatgpt-ai-chatbots-conspiracies.html. (Accessed June 15, 2025)

7. Endsley MR, Caldwell BS, Chiou EK, Cooke NJ, Cummings ML, Gonzalez C, et al. *Human-ai teaming: state of the art and research needs*. Washington (DC): National Research Council, National Academies Press (2021).

8. Brakel F, Odyurt U, Varbanescu AL. Model parallelism on distributed infrastructure: a literature review from theory to llm case-studies. *arXiv* (2024). doi:10.48550/arXiv.2403.03699

9. Brooks R. Why today's humanoids won't learn dexterity. *ESSAYS* (2025) 9/26. Available online at: rodneybrooks.com/why-todays-humanoids-wont-learn-dexterity/. (Accessed September 28, 2025).

10. Greenberger D, Horne M, Zeilinger A. Multipariicle interferometry and the superposition principle. *Phys Today* (1993) 46:22–9. doi:10.1063/1.881360

11. Schölkopf B, Locatello F, Bauer S, et al. Towards causal representation learning. *arXiv:2102.11107* (2021).

12. Marinsek NL, Gazzaniga MS. Split-brain perspective on illusionism. *J Conscious Stud* (2016) 23(11–12):149–59. doi:10.48550/arXiv.2102.11107

13. Baumeister R, Campbell J, Krueger J, Vohs K. Exploding the self-esteem myth. *Scientific Am* (2005) 292(1):84–91. doi:10.1038/scientificamerican0105-84

14. Blanton H, Klick J, Mitchell G, Jaccard J, Mellers B, Tetlock PE. Strong claims and weak evidence: reassessing the predictive validity of the iat. *J Appl Psychol* (2009) 94(3):567–82. doi:10.1037/a0014665

15. Berenbaum MR. Retraction for shu et al., signing at the beginning makes ethics salient and decreases dishonest self-reports in comparison to signing at the end. *PNAS* (2021) 118(38):e2115397118. doi:10.1073/pnas.21153971

16. Nosek B. Estimating the reproducibility of psychological science. *Science* (2015) 349(6251):943. doi:10.1126/science.aac4716

17. Lawless WF, Moskowitz IS. Editorial: special issue. An entropy approach to interdependent human-machine teams. *Entropy* (2025) 27(2):176. doi:10.3390/e27020176

18. Metz C. *It's smart, but for now, people are still smarter*. New York, NY; The New York Times Company (2025). Available online at: https://www.nytimes.com/2025/05/16/technology/what-is-agi.html. (Accessed May 25, 2025)

19. Lawless WF, Moskowitz IS, Doctor K. A quantum-like model of interdependence for embodied human-machine teams: reviewing the path to autonomy facing complexity and uncertainty. *Entropy* (2023) 25(1323):1323. doi:10.3390/e25091323

20. Cassidy J. *Capitalism and its critics: a history: from the industrial revolution to AI*. Straus Giroux: Farrar (2025).

21. Bengio Y, Hinton G, Yao A, Song D, Abbeel P, Darrell T, et al. Managing extreme ai risks amid rapid progress. Preparation requires technical research and development, as well as adaptive, proactive governance. *Science* (2024) 384(6698):842–5. doi:10.1126/science.adn0117

22. Niederhoffer K, Kellerman GR, Lee A, Liebscher A, Rapuano K, Hancock JT AI - generated "workslop" is destroying productivity. *Harv Business Rev* (2025). Available online at: https://hbr.org/2025/09/ai-generated-workslop-is-destroying-productivity.

23. Shojaee P, Mirzadeh I, Alizadeh K, Horton M, Bengio S, Farajtabar M. The illusion of thinking: understanding the strengths and limitations of reasoning models *via* the lens of problem complexity. *Machine Learn Res* (2025) 2. doi:10.70777/si.v2i6.15919

24. Betley J, Tan D, Warncke N, Sztyber-Betley A, Bao X, Soto M, et al. Emergent misalignment: narrow finetuning can produce broadly misaligned llms. *arXiv* (2025). doi:10.48550/arXiv.2502.17424

25. Challapally A, Pease C, Raskar R, Chari R. The genAI divide. State of AI in business 2025. Technical report. MIT Media Lab (2025). Available online at: https://www.artificialintelligence-news.com/wp-content/uploads/2025/08 (Accessed September 27, 2025).

26. Noether E. Invariante variationsprobleme. *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse* (1918) 235–57.

27. Cummings J. Team science successes and challenges. In: *NSF workshop fundamentals of team science and the science of team science*. Bethesda MD (2015).

28. Shehata M, Cheng M, Leung A, Tsuchiya N, Wu DA, Tseng CH, et al. Team flow is a unique brain state associated with enhanced information integration and interbrain synchrony. *eNeuro* (2021) 8(5):ENEURO.0133. doi:10.1523/ENEURO.0133-21.2021

29. Aerts D, Beltran L, de Bianchi MS, Sozzo S, Velez T. Quantum cognition beyond hilbert space I: fundamentals. *Computer Sci* (2016). doi:10.1007/978-3-319-52289-0_7

30. Nash JF. Equilibrium points in n-person games. *PNAS* (1950) 36(1):48–9. doi:10.1073/pnas.36.1.48

31. Perolat J, De Vylder B, Hennes D, Tarassov E, Strub F, de Boer V, et al. Mastering the game of stratego with model-free multiagent reinforcement learning. *Science* (2022) 78(6623):990–6. doi:10.1126/science.add4679

32. Liu Z, Chen YC, Ao P. Entangled biphoton generation in the myelin sheath. *Phys Rev E* (2024) 110:024402. doi:10.1103/PhysRevE.110.024402

33. Khrennikov A, Basieva I, Dzhafarov EN, Busemeyer JR. Quantum models for psychological measurements: an unsolved problem. *PLoS One* (2014) 9(10):e110909. doi:10.1371/journal.pone.0110909

34. Gershenfeld N. *The physics of information technology*. Cambridge University Press (2000).

35. Dwyer S. Squeezing quantum noise. *Phys Today* (2014) 67(11):72–3. doi:10.1063/PT.3.2596

36. Bohr N. Causality and complementarity. *Philos Sci* (1937) 4(3):289–98. doi:10.1086/286465

37. Christensen CM, Alton R, Rising C, Waldeck A. The big idea: the new M-and-A playbook. *Harv Business Rev* (2011). Available online at: https://hbr.org/2011/03/the-big-idea-the-new-ma-playbook

38. Axelrod R. *The evolution of cooperation*. Basic (1984).

39. Lawless WF. The entangled nature of interdependence bistability, irreproducibility and uncertainty. *J Math Psychol* (2017) 78:51–64. doi:10.1016/j.jmp.2016.11.001

40. Marcuse H. *One-dimensional man. Studies in the ideology of advanced industry*. London: Routledge (1964).

41. Lawless W, Moskowitz IS. Shannon holes, black holes and knowledge: can a machine become a "self-aware" teammate? *Knowledge* (2024) 4(3):331–57. doi:10.3390/knowledge4030019

42. Lawless WF. Interdependent autonomous human-machine systems: the complementarity of fitness, vulnerability and evolution, entropy. *Entropy* (2022) 24(9):1308. doi:10.3390/e24091308

43. Suleiman Y. *A war of words. Language and conflict in the Middle East*. Cambridge University Press (2012).

44. Lawless WF, Akiyoshi M, Angjellari-Dajcic F, Whitton J. Public consent for the geologic disposal of highly radioactive wastes and spent nuclear fuel. *Int J Environ Stud* (2014) 71(1):41–62. doi:10.1080/00207233.2014.881165

45. Andrade G, Stafford E. Investigating the economic role of mergers. *J Corporate Finance* (2004) 10:1–36. doi:10.1016/s0929-1199(02)00023-8

46. Chatterjee S. Gains in vertical acquisitions and market power: theory and evidence. *Acad Manage J* (2017) 34(2):436–48. doi:10.2307/256450

47. Schelling TC. *The threat that leaves something to chance*. HDA1631: Rand Corporation (1959).

48. Wong M, Cleland CE, Arend D, Jr, Bartlett S, Cleaves HJ, 2nd, Demarest H, et al. On the roles of function and selection in evolving systems. *PNAS* (2023) 120(43):e2310223120. doi:10.1073/pnas.2310223120

49. Johnston AC, Jones MR, Pope NG. Divorce, family arrangements, and children's adult outcomes. *Tech Rep 25-28, Cent Econ Stud (CES) Census.Gov: ces/CES-WP-25-28.Pdf* (2025).

50. Baer J. A simpler citigroup begins to take shape. In: *CEO jane fraser moves closer to a spinoff of Mexican consumer bank banamex*. Manhattan, NY; Dow Jones and Company (2024). Available online at: https://www.wsj.com/finance/banking/citigroup-banamex-split-jane-fraser-089f9d53. (Accessed October 30, 2024)

51. Bednar RL, Peterson SR. *Self-esteem paradoxes and innovations in clinical practice, 2nd edition*. American Psychological Association APA (1995).

52. Hagger M, Chatzisarantis N, Alberts H, Anggono CO, Batailler C, Birt AR, et al. A multilab preregistered replication of the ego-depletion effect. *Perspect Psychol Sci* (2016) 11(4):546–73. doi:10.1177/1745691616652873

53. Kahneman D. *Thinking fast and slow*. New York, NY: Holtzbrinck Publishing Group (2013).

54. Protzko J, Krosnick J, Nelson L, Nosek BA, Axt J, Berent M, et al. Retraction note: high replicability of newly discovered social-behavioural findings is achievable. *Nat Hum Behav* (2024) 8:2067. doi:10.1038/s41562–024–01997–3

55. Festinger L. *A theory of cognitive dissonance*. Stanford University Press (1957).

56. Axsom D, Cooper J. Cognitive dissonance and psychotherapy: the role of effort justification in inducing weight loss. *J Exp Social Psychol* (1985) 21(2):149–60. doi:10.1016/0022-1031(85)90012-5

57. Axsom D, Lawless WF. Subsequent behavior can erase evidence of dissonance-induced attitude change. *J Exp Social Psychol* (1992) 28:387–400. doi:10.1016/0022-1031(92)90052-l

58. Dat NT, Mitsui N, Asakura S, Takanobu K, Fujii Y, Toyoshima K, et al. The effectiveness of self-esteem-related interventions in reducing suicidal behaviors: a systematic review and meta-analysis. *Front Psychiatry (Section: tPublic Ment Health)* (2022) 13:925423. doi:10.3389/fpsyt.2022.925423

59. Klonsky ED, May AM, Saffer BY. Suicide, suicide attempts, and suicidal ideation. *Annu Rev Clin Psychol* (2016) 12:307–30. doi:10.1146/annurev-clinpsy-021815-093204

60. Klonsky ED, Dixon-Luinenburg T, May AM. The critical distinction between suicidal ideation and suicide attempts. *World Psychiatry* (2021) 20(3):439–41. doi:10.1002/wps.20909

61. Engineering National Academies of Sciences and Medicine (NASEM). *Development, implementation, and evaluation of community-based suicide prevention grants programs: proceedings of a workshop*. Washington, D.C.: National Academies Press (2025).

62. Dorfman Z. Moscow's spies were stealing us tech — until the FBI started a sabotage campaign. In: *During the early days of silicon valley, a tech industry entrepreneur teamed up with the FBI to ship faulty devices to Moscow*. Virginia, U.S: Axel Springer (2024). Available online at: https://www.politico.com/news/magazine/2024/08/04/us-spies-soviet-technology-00164126.

63. Bhattacharjee Y. The daring ruse that exposed china's campaign to steal american secrets. In: *How the downfall of one intelligence agent revealed the astonishing depth of chinese industrial espionage*. New York, NY: The New York Times Company (2023).

64. Gutmann DF, Thompson A. *The spirit of compromise. Princeton U*. Princeton University Press (2014).

65. Smith A. *An inquiry into the nature and causes of the wealth of nations*. University of Chicago Press (1977). p. 1776.

66. Lawless WF, Castelao T, Ballas JA. Virtual knowledge: bistable reality and the solution of ill-defined problems. *IEEE Syst Man, Cybernetics* (2000) 30(1):119–26. doi:10.1109/5326.827482

67. US State Department. The chinese communist party: china's disregard for human rights. Technical report. Washington, DC: US State Department (2017). Available online at: https://2017-2021.state.gov/chinas-disregard-for-human-rights/ (Accessed September 28, 2025).

68. Cohen L. *Time-frequency analysis*. Hoboken, NJ: Prentice Hall (Simon and Schuster) (1995).

69. Nakamura J, Csikszentmihalyi M. The concept of flow. In: CR Snyder, SJ Lopez, editors. *Handbook of positive psychology*. Oxford University Press (2002). p. 89–105.

70. Service RF. AI-driven robots discover record-setting laser compound. automated labs spread across the globe create, test, and assemble materials–no humans required. *Science* (2024) 384(6697):725. doi:10.1126/science.zgwwhjc

71. NHTSA. Alcohol ignition interlocks. *National highway traffic safety administration*. Washington, DC: U.S. Department of Transportation (2025). Available online at: https://www.nhtsa.gov/book. (Accessed May 7, 2025)

72. US DOT. *Positive train control (PTC)*. Washington, DC: U.S. Department of Transportation (2025). Available online at: https://railroads.dot.gov. (Accessed May 7, 2025)

73. Centeno G. F-16: how the fighter has evolved 50 years after its first flight (2024).

74. DiMascio J. U.S. air force collaborative combat aircraft (CCA). *CRS Prod (Library Congress)*. Available online at: https://www.congress.gov/crs-product/IF12740#::text=The2025 (Accessed October 28, 2025).

75. Cooke NJ, Blandford RD, Cummings JN, Fiore SM, Hall KL, Jackson JS, et al. *Enhancing the effectiveness of team science*. Washington (DC): National Research Council, National Academies Press (2015).

76. Engineering National Academies of Sciences and Medicine (NASEM). *Human and organizational factors in AI risk management: proceedings of a workshop*. Washington, DC: National Academies Press (2025).

77. Ledebt A. Changes in arm posture during the early acquisition of walking. *Infant Behav Development* (2000) 23:79–89. doi:10.1016/S0163–6383(00)00027–8

78. Winston GC. Addiction and backsliding: a theory of compulsive consumption. *J Econ Behav Organ* (1980) 1(4):295–324. doi:10.1016/0167-2681(80)90009-8

79. Wickens CD. *Engineering psychology and human performance*. 2nd edn. Merrill (1992).

80. Gordon R. *Can robots learn from machine dreams? MIT CSAIL researchers used ai-generated images to train a robot dog in parkour, without real-world data*. MIT News (2025). Available online at: https://news.mit.edu/2024/can-robots-learn-machine-dreams-1119 (Accessed September 13, 2025).

81. Cross JI, Ryley T. Assessing evidence-based training in a collaborative virtual reality flight simulator. *The Aeronaut J* (2025) 129(1332):261–81. doi:10.1017/aer.2024.113

82. Costa AN, Dantas JPA, Scukins E, Medeiros FLL, Ögren P. Simulation and machine learning in beyond visual range air combat: a survey. *IEEE Access* (2025) 13:76755–74. doi:10.1109/ACCESS.2025.3563811

83. Burley D, Wang M, Carter D, Chiou EK-L, Diazgranados D, Fiore SM et al. The science and practice of team science. Technical report. Washington, DC: National Academies Press (2025). Available online at: https://nap.nationalacademies.org/catalog/29043/the-science-and-practice-of-team-science. (Accessed August 13, 2025)

84. Sarris A. *The American cinema: directors and directions, 1929–1968*. New York, NY: Grand Central Publishing (1996).

85. Pribram KH. Quantum holography: is it relevant to brain function? *Inf Sci* (1999) 115(1–4):97–102. doi:10.1016/S0020-0255(98)10082-8

86. Mehrabian A. *Silent messages*. Wadsworth (1971).

87. Fedorenko E, Piantadosi ST, Gibson EAF. Language is primarily a tool for communication rather than thought. *Nature* (2024) 630:575–86. doi:10.1038/s41586-024-07522-w

88. Stix G. You don't need words to think. In: *Brain studies show that language is not essential for the cognitive processes that underlie thought*. Scientific American (2024). Available online at: https://www.scientificamerican.com/article/you-dont-need-words-to-think. (Accessed October 13, 2025)

89. Huang R, Chin J. Humanoid robots are lousy co-workers. China wants to be first to change that. *Wall Street J* (2025). Available online at: https://www.wsj.com/tech/ai/humanoid-robots-are-lousy-co-workers-china-wants-to-be-first-to-change-that-0fe8528c.

90. Lacey J. Artificial general intelligence in competition and war. *Real Clear Defense* (2025). Available online at: https://www.realcleardefense.com/articles/2025/05/07/artificial_general_intelligence_in_competition_and_war_1108660.html. (Accessed May 7, 2025)

91. Mims C. We now know how AI 'thinks'—and it's barely thinking at all. *Wall Street J* (2025). Available online at: https://www.wsj.com/tech/ai/how-ai-thinks-356969f8 (Accessed March 26, 2025).

92. Aronson E, Mills J. The effect of severity of initiation on liking for a group. *J Abnormal Social Psychol* (1959) 59(2):177–81. doi:10.1037/h0047195

93. Schleihauf H, Sanford EM, Thompson BD, Zhang S, Rukundo J, Call J, et al. Chimpanzees rationally revise their beliefs. *Science* (2025) 390(6772):521–6. doi:10.1126/science.adq5229

94. Ginsburg RB. American electric power co., inc. Washington, DC: United States Reports (2011). p. 10–174.

95. Lewin K. *Field theory in social science. Selected theoretical papers*. Harper and Brothers (1951).

96. White Paper. European governance (com.428 final). In: *Commission of the european community* (2001).

97. Abbot D, Davies PCW, Pati AK. Forward. In: *Quantum aspects of life*. London: Imperial College Press (2008).

98. Ponce de León MS, Bienvenu T, Marom A, Engel S, Tafforeau P, Alatorre Warren JL, et al. The primitive brain of early homo. *Science* (2021) 372(6538):165–71. doi:10.1126/science.aaz0032

99. Mokyr J. Sustained economic growth through technological progress. In: *Scientific background to the sveriges riksbank prize in economic sciences in memory of alfred nobel 2025* (2025). Available online at: https://www.nobelprize.org/uploads/2025/10/advanced-economicsciencesprize2025.pdf (Accessed May 11, 2025).

100. Tetlock PE. *Superforecasting: the art and science of prediction*. New York, NY: Crown Publishing (Penguin Random House) (2015).

101. Ott R, Zache TV, Prüfer M, Erne S, Tajik M, Pichler H, et al. Hamiltonian learning in quantum field theories. *arXiv: 2401.01308v1* (2024) 6:043284. doi:10.1103/physrevresearch.6.043284

102. Simon HA. What is an explanation of behavior? *Psychol Sci* (1992) 3:150–61. doi:10.1111/j.1467-9280.1992.tb00017.x