



Introduction

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The evolutionary past and future of collective intelligence: introduction to the theme issue

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Collective intelligence (CI)—the ability of groups to find solutions to problems and make decisions more effectively than their individual members—is a prominent feature of many group-living species, including our own. In this introductory article of the theme issue, we review and synthesize research concerning the evolution of CI from a range of disciplines, drawing in particular on the contributions made to the current issue. We describe mechanisms that generate CI and how they manifest across species, prompting insights into CI's evolutionary history and phylogeny. We consider the functions and cognitive underpinnings of CI in the hominin lineage and in our own species, drawing on archaeological and ethnographic data. We summarize contemporary applied research and discuss the future of CI in human societies. Key questions raised in this introduction and tackled by the theme issue include: to what extent are different manifestations of CI across species phylogenetically related? How important are communication, deliberation or culture for leveraging the potential of groups? And how can scientific and technological advancements improve the human capacity for collective problem-solving and decision-making?

This article is part of the theme issue 'The evolution of collective intelligence'.

1. Introduction: the scientific history of collective intelligence

Collective intelligence (CI) refers to the phenomenon whereby groups of individuals are able to surpass the abilities of their individual members to make decisions and find solutions to problems [1,2]. The observation that, through emergent properties of collective behaviour, groups can outperform the aggregate skills of their constituent members dates back at least to Aristotle, who conjectured in *The Politics* in the fourth century BCE that 'the many, of whom each individually is not a good man, when they meet together may be better than the few good'—a doctrine dubbed the 'wisdom of the multitude' [3]. Similar observations were made over the centuries in different fields. In the fourteenth century CE, the Arab scholar Ibn Khaldun used the term '*asabiyyah*' to describe the social cohesion that enabled the coordinated activity by which

tribal groups defended and expanded their boundaries [4]. In *The Wealth of Nations* (1776), Adam Smith used the metaphor of an invisible hand to describe how public benefits were maximized by individuals pursuing their own private interests; later, economists such as Friedrich Hayek have referred to these sorts of emergent collective benefits as ‘spontaneous order’ (see [5]). Nicholas de Condorcet’s Jury Theorem (1785) demonstrated that the majority opinion of a group of informed but imperfect judges is more reliable than any individual judgement under the right conditions, and in the early twentieth century Francis Galton famously showed how averaging the guesses of a crowd regarding the weight of an ox generated the most accurate estimate [6]. Finally, the nineteenth and twentieth centuries saw an increasing recognition of the importance of mutualism and cooperation in both human and non-human societies, influenced by the work of anarchist philosopher Peter Kropotkin [6], and later formalized by evolutionary biologists including W.D. Hamilton [7] and Robert Trivers ([8]; see [9] for a summary).

The contemporary usage of the term ‘collective intelligence’ originates in the work of psychologist David Wechsler [10,11], although it gained popularity in the computer science literature towards the end of the twentieth century [12–18], as emerging technologies in network connectivity and machine learning demonstrated the promise of harnessing humanity’s collective knowledge and capabilities at hitherto impossible scale. In the 1990s and 2000s, CI research garnered interest in the world of business and management [19,20] as well as in the popular imagination, with the publication of books such as *The Wisdom of Crowds* [21]. During this same time period, several key texts in philosophy explored the idea of collective agency, beliefs and intentionality [22–27]. The past 15 years have seen a proliferation of academic research on CI, measuring and quantifying its effect on group performance [28–33], exploring the interplay between culture and collective adaptation [34,35], analysing the role of network shape and structure on CI [36], studying how groups learn and transmit information [37–39], and applying its insights to political science [40], governance and decision-making [41], scientific best practice [42], medicine [43] and biological systems [44].

Predating and—mostly—parallel to this blossoming pluridisciplinary research, the biological fields of ethology, behavioural ecology, and evolutionary anthropology and psychology have long been interested in collective behaviour, cooperation, culture and group decision-making [45–51]. The aim of this theme issue is to bridge insights from the evolutionary behavioural sciences with contemporary CI research to help develop a comprehensive picture of the evolutionary origins, forms, functions and future of CI. In this introduction, we analyse CI through the lens of the four ‘major problems of biology’ identified by biologist Nikolaas Tinbergen that must be explained in order to understand a biological trait [52,53], namely the mechanisms that generate it, the adaptive purpose it serves, the way it emerges in individuals and collectives and its evolutionary origins and history. Following the structure of the theme issue, we first explore the forms and function of CI in non-human animals, using a phylogenetic perspective; next, we examine its role in human evolution and across the ethnographic record; and finally we investigate contemporary and future applications of CI.

2. The forms and functions of collective intelligence across species

Emergent group intelligence, arising from self-organizing systems, may be as old as any form of individual cognition. Self-organization refers to the complex patterns of group behaviour that emerge spontaneously from relatively simple individual actions and interactions [46,54]. Canonical examples of adaptive self-organization include ant trails [55–57] and the complex movement of schools of fish [58,59] or herds of wildebeest [60]. This kind of group-level behaviour addresses problems, such as navigation or protection from predators, more effectively than could be achieved by individuals, and can therefore properly be understood as a basic form of collective intelligence. Recently, researchers have applied this concept to the behaviour of bacterial colonies and ecosystems [61–63] and even to the internal organization and development of multicellular organisms [44]. Self-organization behaviour has also been studied in humans, notably in the behaviour of crowds [64,65]. The individual cognitive prerequisites for group self-organization may be relatively minimal [46], but include at least the ability to seek out a certain outcome (such as avoiding predation) and to process information about relative positioning and movement in an environment. This allows the cognitive processing power of the group to be distributed not only among the minds of its constituents, but also to the environment with which it engages [66]. Once self-organization emerges in a collective, further selection can shape its ability to solve problems of increasing complexity.

In both humans and non-humans, the ability to coordinate as part of a group can significantly improve collective problem-solving and decision-making [67]. Learning, communicating and aggregating information are all important processes underlying group decision-making. In honey-bees, for example, scouts use waggle dances to communicate sources of nectar to their hive mates [68,69], who come to a consensus decision on which location to harvest [70], improving foraging efficiency [71] and helping to avoid mistakes due to individual error [72]. Pairs of homing pigeons flying together have been shown to average their preferred trajectories to chart a compromise course [73]. Ants pool information about potential nest sites in a deliberative process [74], and in this issue, Gildea *et al.* [75] demonstrate that ants make visual associations more rapidly when learning collectively in colonies as opposed to individually, illustrating the adaptive function of CI in ant cognitive development. Consensus decision-making of one form or another has been reported in a wide range of animal species [47], although rarely does each member have equal influence over the group’s decisions. More common is the outsized influence of one or a small number of group members, also known as leadership [76,77]. Leadership enables groups to reach collective decisions in situations where simple individual heuristics fail [78] by deferring to individuals who coordinate movement or otherwise initiate group behaviours. Leadership in this form has been observed in fish [79], birds [73,80] and is very common in social mammals [76], including humans, as we discuss in the next section. Leadership should not be conflated with dominance hierarchies [81–83], as dominance relies on physical coercion which loses efficacy when applied to groups. Instead, leadership requires some amount of willing deference on the part of followers; emergent leaders may be dominant [76], but they could also be more knowledgeable [84], or in greater need [85], or they may simply be the first to initiate movement [86].

One of the most valuable benefits of group communication and information transfer is the ability to store and evolve cultural knowledge. Cultural transmission enables CI by allowing information or skills to spread in a group that improve its efficacy, that individual members would be unlikely to discover alone. Biologists have recorded examples of socially transmitted cultural traditions in non-human animals across a wide range of taxa [87]. Capuchin monkeys transmit group-specific games, social traditions and foraging techniques [88–90]. Humpback whale songs are transmitted and evolve culturally [91–93]. Pigeons [94], bees [95] and fruit flies [96,97] have been shown experimentally to transmit learnt behaviours and preferences to each other, initiating long-lasting cultural traditions. Brooker *et al.* [98] demonstrate collective information storage in ape populations using behavioural experiments and they test the impact of social structure—including group cohesiveness and stability—on group-level information storage and collective intelligence. The capacity for cultural transmission in non-humans is well documented, but its adaptive value in those species remains less well understood. Theoretical work has suggested that cultural transmission can both stabilize normative practices [66] and help species avoid the costs of individual exploration, especially when environmental conditions change faster than natural selection can track [99,100].

In humans, the cumulative, ratcheting nature of cultural innovation has been singled out as one of the most important drivers of human success [101,102]. By contrast, the existence of cumulative cultural evolution (CCE) in non-humans remains the subject of some debate [87,103,104]. Experimental research using transmission chains has demonstrated incremental improvements over time in homing pigeons pathing routes [94], and performance on memory tasks among baboons [105], while observational studies have suggested the presence of CCE in bighorn sheep [106] and humpback whales [93], and spatial and genetic analysis has shown that some form of ‘incipient’ cumulative culture may exist in chimpanzees [107]. In this issue, Vinicius *et al.* [108] develop a framework for identifying and explaining CCE that includes empirical examination of population-level trait distribution and focuses on both proximate and ultimate explanations for collective intelligence.

To summarize, let us return to Tinbergen’s four questions concerning mechanisms, phylogeny, development and adaptive function. Collective intelligence in non-humans appears to be underpinned by a variety of mechanisms, from statistical aggregation and emergent properties of large numbers of simple interactions, to communication, consensus-building, division of labour, social learning and culture. A single unifying framework for understanding these varying forms of CI remains somewhat elusive, although progress is being made. For example, Anwarzai *et al.* [109] classify forms of CI along two dimensions of information processing: individual processing of group information and group processing of individual information. In this framework, statistical aggregation requires low levels of information processing, while self-organization requires individual- but not group-level processing, and complex organizational structures require both forms. Thus, different forms of CI require different cognitive, social and structural pre-requisites, which must be taken into account when developing a phylogenetic or cross-species comparative analysis of CI, and whose developmental pathways and triggers must be studied separately. In this issue, Rawlings *et al.* [110] identify five mechanisms underpinning CI and compare them across two distantly related species, rats and cockroaches, that share important ecological and behavioural traits, contrasting low-requirement, generalized forms of CI common to many or all collectives and specialized forms dependent on complex or derived cognitive adaptations. The fourth evolutionary question, that of adaptive function, is the most generalizable across different forms of CI. The adaptive benefits of collective intelligence are to dramatically reduce the individual cognitive requirements necessary to achieve complex and effective group-level outcomes, and to produce synergistic or ‘emergent’ behaviours that are only possible through cooperative coordination [111]. We explore some of these adaptive benefits in this issue: first, Warren *et al.* [112] experimentally test the ability of pairs of chimpanzees to jointly cover for mutually exclusive outcomes using an inverted U-shaped tube which could yield a reward from either end. Next, comparing how members of different species approach similar problems while leveraging CI in different ways can illuminate the relationship between cognition and collective problem-solving. To this end, Koomen [113] reviews collective strategies to avoid common pool resource dilemmas in humans and non-human species.

3. Collective intelligence in human evolution and development

Humans have long been recognized as the quintessentially cooperative species [114]. Our evolutionary success has been attributed to extensive cooperation with non-relatives [115], ability to develop institutions [116] and cultural capacity to share and progressively improve knowledge, skills and technology [101,117]. The human evolutionary ecological niche relies on food that is calorically dense, difficult to obtain or to process for consumption, and with high return variance, including meat, roots and nuts [118]. To support this, humans have evolved exceptionally advanced cognitive capacities, which in turn require extended juvenile periods supported by intergenerational transfers [119], cooperative breeding [120,121], reciprocal sharing networks [122], divisions of labour [123,124] and high levels of in-group altruism [125]. Extended networks of cooperation and exchange have likely been features of human and hominin societies deep into our evolutionary past [126]. In this issue, Brooker *et al.* [98] argue for the importance of social structure to collective and distributed cognition, while Vadavalli *et al.* [127] explore through agent-based modelling how social structure, and specifically the kinship structure of a population, might impact information flow and consensus decision-making.

The human capacity for language and symbolic representation enabled efficient coordination and communication, unlocking a critical tool for collective intelligence [128] and culture [129]. In this theme issue, Koymen & Waddington [130] examine the emergence of collective reasoning in young children, showing how even at an early age children are able to reason with a partner to share knowledge and improve their joint problem-solving ability. Humans are quintessential social learners [131,132], but cross-cultural evidence shows we are equally prolific and universal teachers [133], and our ability to combine faithful transmission of knowledge and skills through teaching alongside our capacity for individual problem-solving and innovation make humans one of the most ecologically adaptable species in Earth’s history [134]. Understanding the evolution of hominin cultural capacity

for CI requires a theoretically structured examination of the material and archaeological record. In this issue, d'Errico *et al.* [135] argue that CI evolved in hominins through epistemic niche construction, and propose criteria to define this phenomenon and identify it in the archaeological record. Using a modelling approach, Winters & Charbonneau [136] argue that the open-ended cultural evolution characteristic of humans requires historically contingent co-evolution between cultural systems and the needs, problems and goals of a society.

Culture further promotes collective intelligence through cultural norms and institutions, which help solve collective action problems and generate collaboration [137,138]. By encouraging adherence to collective rules, groups are able to foster a sense of shared purpose and identity that unlock collective problem-solving capacity [139]. Two deeply engrained elements of human sociality and cognition help explain our particular success at collective intelligence. First, an aversion to arbitrary inequality. Humans are extremely sensitive to asymmetric social outcomes and have reliably developing preferences for egalitarianism that emerge at young ages and are observed cross-culturally [140]. Most societies in human evolutionary history are likely to have been relatively egalitarian, in the sense of lacking hereditary rulers and stratified social classes [141,142], despite the existence of some hierarchical hunter-gatherer societies and variability in societal organization in the upper Palaeolithic [143]. Egalitarianism in hunter-gatherer groups is maintained by levelling mechanisms such as dissent, ridicule and ostracism applied against individuals who would abuse their position of leadership or authority [144]. This encourages viewpoint diversity, deliberation and consensus building while discouraging despotic or unipolar decision-making [145]. Complementing humans' egalitarian tendencies is our ability to recognize greater knowledge, skill or capacity in others and to defer to their leadership in specific contexts. Leadership is a universally observed feature of human societies [77] and allows groups to resolve conflicts and disagreements, overcome gridlocks and coordinate complex collective tasks [146]. Cross-cultural analysis of small-scale societies shows that a combination of knowledge-based, temporary leadership combined with norms encouraging deliberation, viewpoint diversity and shared group meaning enables communities to avoid both groupthink, where there is insufficient diversity of opinion, and group fission, where disagreements are not able to be resolved [145]. El Aissati *et al.* [147] provide evidence that standard surveys of knowledge (e.g. [148]) which have motivated the claim that technology may develop in the absence of causal understanding [117], may systematically underestimate the knowledge of a group, by overlooking the role of deliberation and information-pooling. They introduce a method that allows individuals to defer to more sophisticated answers provided by others, leading to more effective convergence on correct causal explanations.

Collective reasoning, deliberation, consensus-building and collaboration have deep evolutionary roots in human social cognition. Our capacity for knowledge sharing and collective innovation have allowed us to adapt to and reshape almost all of Earth's environments, generating unprecedented technological opportunities and challenges. In the next section, we discuss contemporary CI research and its applications to these challenges.

4. Contemporary and future applications of collective intelligence

With cultural evolution proceeding at a pace far outstripping that of biological evolution [149,150], the past 250 years of cultural and technological ratcheting have likely been the most transformative in human history. Telecommunication, mass media and internet connectivity have created a shared information space orders of magnitude larger than any that have existed in the past, while neural networks, transformers and modern computer chips have produced knowledge aggregation and reasoning machines that we still barely understand [151]. There are also more humans alive on earth today than ever before, and close to as many as there ever will be. What value can CI research bring to the challenges of twenty-first century society?

One of the most promising areas of development in contemporary CI has been research on democratic innovation and new methods of governance, adapted to large populations and modern technological capabilities. Participatory democracy aims to remove barriers to political inclusion by involving citizens in decision-making processes [152], for example in budgeting [153] and drafting legal and constitutional reforms [154,155]. By leveraging viewpoint diversity, structured deliberation, participatory democracy initiatives like citizens assemblies aim to improve collective decisions while increasing the perceived legitimacy of the democratic process [156–158].

Contemporary educational and scientific tools have likewise benefitted greatly from new tools that leverage CI by crowdsourcing problem-solving. For instance, the Polymath project has leveraged 'massively collaborative mathematics' [159] to search for solutions to unsolved mathematical problems, to notable success (e.g. [160,161]). Similarly, citizen science projects such as FoldIt [162], WeFold [163], Galaxy Zoo [164] and Planet Hunters [165] collectively rely on millions of volunteers to explore otherwise prohibitively large search spaces to classify or discover crystal and protein structures, galaxies and extrasolar planets, respectively, among many other projects. For the dissemination of knowledge, the rapid growth of Massive Open Online Courses (MOOCs) has proven the potential reach and scope of free and widely available educational materials, despite current challenges including high dropout rates and variability in course quality [166]. In this issue, Pykälä *et al.* [167] use agent-based evolutionary modelling to explore how the structure of social networks combine with individual learning strategies to affect collective performance.

CI has also been applied to information aggregation and forecasting. Prediction markets take advantage of the 'wisdom of the crowds' phenomenon while giving individuals the ability to weight their opinion according to their confidence level by spending more money [168]. In this issue, Dietrich & List [169] explore the possibility of aggregating judgements that are non-binary, deriving new mathematical theorems. Large language models, which train on immense corpuses of digitally stored writing, draw their remarkable capabilities from the aggregation of meaning and information generated by humans. The implications of these models for the nature of human collective intelligence are uncertain, as machines play an ever-increasing role in the production and dissemination of knowledge and ideas [170]. The implication is the creation of new possibilities for collective flourishing as

well as new possibilities for disharmony. To that end, Jeddi *et al.* [171] explore how large language models overlap with humans in their ability to make accurate forecasts across different domains.

Finally, CI research can produce key insights into how groups respond to shocks and disruptive events. The scale and interconnectivity of contemporary global society entails major risks of disturbances due to disease, climate change or geopolitical instability [172]. In this issue, Mulgan [173] explores an emerging frontier in how policy makers can integrate data, models, evidence, tacit knowledge, foresight and innovation to solve pressing collective action challenges, while Moussaid *et al.* [174] use an experiment to uncover patterns in the transmission of reactive and protective behaviours in a group following a shock.

5. Collective stupidity and the limits of collective intelligence

Although CI by definition improves group outcomes, it is by no means guaranteed that collective cognition will be an improvement on individual cognition. The opposite of CI, where groups perform worse than they would have as individuals, has been called collective stupidity [175]. For certain problems, particularly simple or straightforward ones, the additional cognitive burden and risk of communication error inherent in joint action may outweigh any plausible benefit of collective cognition. Ants, for instance, may perform better collectively on cognitively demanding tasks but better individually on easier ones [176]; pheromonal communication in ants is also known to fail catastrophically, as in the case of army ant ‘mills’ following each other around in circles to the point of death by exhaustion [177]. Less dramatically, human institutions are often faced with problems of high administrative burden and operational inefficiency [178,179], which hamper their CI potential.

Moreover, if groups are on average misinformed or biased, aggregating large numbers of opinions or desires will lead to worse outcomes, not better; it is a corollary of Condorcet’s theorem, for instance, that *incompetent* voters are guaranteed to make the *wrong* decision as they increase in number. This same concept can explain why ‘big data’ does not always lead to better inferences, since even small biases can be magnified in large samples, leading to faulty conclusions [180]. The claim that voters are incompetent has fuelled philosophical opposition to democracy since Plato [181,182], and irrespective of the merits of these arguments, both the nature of the collective task [183] and the composition of the group [184,185] can certainly impact CI or remove it entirely.

Finally, all groups face the challenge of the conflicting interests of their individual members. Even perfectly rational individual behaviours can result in suboptimal or even catastrophic game theoretical equilibria, such as the ‘tragedy of the commons’ in common-pool resource dilemmas (see Koomen [113]). Many of the most challenging problems facing human societies today are hampered by conflicts of interest within and between nations, economic classes or generations: curbing climate change, for instance, requires weighing the economic well-being of people alive today against the welfare of generations to come. Although the current issue focuses on collective intelligence, understanding where it breaks down, and gives way to collective stupidity, may be an equally valuable and fruitful area of research.

6. Conclusion

Collective intelligence enables groups to overcome the cognitive limitations of its individual members, and may be one of the chief strengths of group-living species. In its most common and elementary form, CI emerges implicitly from simple individual heuristics, as seen in ant colonies or shoals of fish. In some species, however, CI can rely on sophisticated forms of communication, collective decision-making, leadership and culture. Humans are particularly adept at leveraging CI; cultural knowledge, norms and institutions have underpinned human societies throughout our evolutionary history, in small-scale societies and contemporary globalized nation states alike. Institutions such as democratic elections and trials by jury are predicated on the insight that collective decisions are more accurate than individual ones. Here we explored the evolution of CI with an eye on the forms of CI as it appears across species and history, the functions of CI as it allows us to solve different kinds of problems, and the future of CI as new methods of harnessing the power of groups to solve problems efficiently are developed. Bak-Coleman *et al.* [186] have argued that the study of collective behaviour should be thought of as a ‘crisis discipline’—one that is urgently needed given that the challenges facing us today as a species cannot be solved by any individual, or any individual community. Climate change, mass migration, income inequality and other global risks are all problems that face us collectively and require a collective response. These wicked problems implicate many actors and must be solved by drawing on many minds. The current issue aims to present a comprehensive picture of CI through the lens of evolutionary biology while showcasing the value of CI science to collective problems. Our goal is to bridge the gap between CI research across disciplines and spark further collaborative research in this field.

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References

- Malone TW, Bernstein M. 2022 *Handbook of collective intelligence*. Cambridge, MA: MIT Press.
- Boucher S. 2023 *The Routledge Handbook of collective intelligence for democracy and governance*, 1st edn. London, UK: Routledge. (doi:10.4324/9781003215929)
- Waldron J. 1995 The wisdom of the multitude: some reflections on book 3, chapter 11 of Aristotle's *Politics*. *Polit. Theory* **23**, 563–584. (doi:10.1177/0090591795023004001)
- Alagha J. 2017 Ibn Khaldun: a sociology of history. *Int. Sociol.* **32**, 180–188. (doi:10.1177/0268580916687460)
- Petsoulas C. 2013 *Hayek's liberalism and its origins: his idea of spontaneous order and the Scottish Enlightenment*. London, UK: Routledge.
- Paulson L. 2023 In *A brief history of collective intelligence, democracy, and governance*, pp. 3–30, 1st edn. London, UK: Routledge. (doi:10.4324/9781003215929-2)
- Hamilton WD. 1964 The genetical evolution of social behaviour. II. *J. Theor. Biol.* **7**, 17–52. (doi:10.1016/0022-5193(64)90039-6)
- Trivers RL. 1971 The evolution of reciprocal altruism. *Q. Rev. Biol.* **46**, 35–57. (doi:10.1086/406755)
- Dugatkin LA. 1997 The evolution of cooperation. *Bioscience* **47**, 355–362. (doi:10.2307/1313150)
- Wechsler D. 1958 *The measurement and appraisal of adult intelligence*, 4th edn. Baltimore, MD: Williams & Wilkins Co. (doi:10.1037/11167-000). See <https://content.apa.org/books/11167-000>.
- Wechsler D. 1971 Concept of collective intelligence. *Am. Psychol.* **26**, 904–907. (doi:10.1037/h0032223)
- Hiltz SR, Turoff M. 1978 *The network nation: human communication via computer*. Reading, MA: Addison-Wesley.
- Mataric MJ. 1992 Designing emergent behaviors: from local interactions to collective intelligence. In *Proc. 2nd Int. Conf. on Simulation of Adaptive Behavior*, pp. 432–441. Cambridge, MA: MIT Press.
- Engelbart DC. 1995 Toward augmenting the human intellect and boosting our collective IQ. *Commun. ACM* **38**, 30–32. (doi:10.1145/208344.208352)
- Smith JB. 1994 *Collective intelligence in computer-based collaboration*. Boca Raton, FL: CRC Press.
- Levy P. 1994 *Pour une anthropologie du cyberspace*. Paris, France: La Découverte.
- Heylighen F. 1999 Collective intelligence and its implementation on the web: algorithms to develop a collective mental map. *Comput. Math. Organ.* **5**, 253–280. (doi:10.1023/A:1009690407292)
- Szuba TM. 2001 *Computational collective intelligence*. Hoboken, NJ: John Wiley & Sons, Inc.
- Pór G. 1995 The quest for collective intelligence. In *Community building: renewing spirit and learning in business* (ed. K Gozdz). San Francisco, CA: New Leaders Press.
- Isaacs W. 1999 *Dialogue: and the art of thinking together*. New York, NY: Doubleday.
- Surowiecki J. 2004 *The wisdom of crowds: why the many are smarter than the few and how collective wisdom shapes business, economies, societies, and nations*. New York, NY: Doubleday & Co.
- Gilbert M. 1992 *On social facts*. Princeton, NJ: Princeton University Press. (doi:10.1515/9780691214627). See <https://www.degruyterbrill.com/document/doi/10.1515/9780691214627/html>.
- List C, Pettit P. 2011 *Group agency: the possibility, design, and status of corporate agents*. Oxford, UK: Oxford University Press.
- Pettit P. 1996 *The common mind: an essay on psychology, society, and politics*. New York, NY: Oxford University Press.
- Searle JR. 1997 *The construction of social reality*. New York, NY: Free Press.
- Tollefsen D. 2015 *Groups as agents*. Malden, MA: Polity.
- Tuomela R. 2007 *The philosophy of sociality: the shared point of view*, 1st edn. New York, NY: Oxford University Press. (doi:10.1093/acprof:oso/9780195313390.001.0001)
- Woolley AW, Chabris CF, Pentland A, Hashmi N, Malone TW. 2010 Evidence for a collective intelligence factor in the performance of human groups. *Science* **330**, 686–688. (doi:10.1126/science.1193147)
- Woolley AW, Gupta P. 2024 Understanding collective intelligence: investigating the role of collective memory, attention, and reasoning processes. *Perspect. Psychol. Sci.* **19**, 344–354. (doi:10.1177/17456916231191534)
- Woolley AW, Aggarwal I, Malone TW. 2015 Collective intelligence and group performance. *Curr. Dir. Psychol. Sci.* **24**, 420–424. (doi:10.1177/0963721415599543)
- Riedl C, Kim YJ, Gupta P, Malone TW, Woolley AW. 2021 Quantifying collective intelligence in human groups. *Proc. Natl Acad. Sci. USA* **118**, e2005737118. (doi:10.1073/pnas.2005737118)
- Massari GF, Giannoccaro I, Carbone G. 2019 Are distrust relationships beneficial for group performance? The influence of the scope of distrust on the emergence of collective intelligence. *Int. J. Prod. Econ.* **208**, 343–355. (doi:10.1016/j.jipe.2018.12.005)
- Mahmoodi A et al. 2015 Equality bias impairs collective decision-making across cultures. *Proc. Natl Acad. Sci. USA* **112**, 3835–3840. (doi:10.1073/pnas.1421692112)
- Muthukrishna M, Henrich J. 2016 Innovation in the collective brain. *Phil. Trans. R. Soc. B* **371**, 20150192. (doi:10.1098/rstb.2015.0192)
- Galesic M et al. 2023 Beyond collective intelligence: collective adaptation. *J. R. Soc. Interface* **20**, 20220736. (doi:10.1098/rsif.2022.0736)
- Centola D. 2022 The network science of collective intelligence. *Trends Cogn. Sci.* **26**, 923–941. (doi:10.1016/j.tics.2022.08.009)
- Jayles B, Escobedo R, Cezeza S, Blanchet A, Kameda T, Sire C, Theraulaz G. 2020 The impact of incorrect social information on collective wisdom in human groups. *J. R. Soc. Interface* **17**, 20200496. (doi:10.1098/rsif.2020.0496)
- Granovskiy B, Gold JM, Sumpter DJT, Goldstone RL. 2015 Integration of social information by human groups. *Top. Cogn. Sci.* **7**, 469–493. (doi:10.1111/tops.12150)
- Smaldino PE, Moser C, Pérez Velilla A, Werling M. 2024 Maintaining transient diversity is a general principle for improving collective problem solving. *Perspect. Psychol. Sci.* **19**, 454–464. (doi:10.1177/17456916231180100)
- Landemore H. 2012 The mechanisms of collective intelligence in politics. In *Collective wisdom: principles and mechanisms* (eds H Landemore, J Elster), pp. 251–289. Cambridge, UK: Cambridge University Press. (doi:10.1017/CBO9780511846427.012)
- Danaher J et al. 2017 Algorithmic governance: developing a research agenda through the power of collective intelligence. *Big Data Soc.* **4**, 205395171772655. (doi:10.1177/2053951717726554)

42. Woolley AW, Fuchs E. 2011 PERSPECTIVE—collective intelligence in the organization of science. *Organ. Stud.* **22**, 1359–1367. (doi:10.1287/orsc.1110.0648)
43. Kurvers RHJM, Herzog SM, Hertwig R, Krause J, Carney PA, Bogart A, Argenziano G, Zalaudek I, Wolf M. 2016 Boosting medical diagnostics by pooling independent judgments. *Proc. Natl Acad. Sci. USA* **113**, 8777–8782. (doi:10.1073/pnas.1601827113)
44. McMillen P, Levin M. 2024 Collective intelligence: a unifying concept for integrating biology across scales and substrates. *Commun. Biol.* **7**, 378. (doi:10.1038/s42003-024-06037-4)
45. Whiten A, Biro D, Bredeche N, Garland EC, Kirby S. 2022 The emergence of collective knowledge and cumulative culture in animals, humans and machines. *Phil. Trans. R. Soc. B* **377**, 20200306. (doi:10.1098/rstb.2020.0306)
46. Sumpter DJT. 2006 The principles of collective animal behaviour. *Phil. Trans. R. Soc. B* **361**, 5–22. (doi:10.1098/rstb.2005.1733)
47. Conradt L, Roper TJ. 2005 Consensus decision making in animals. *Trends Ecol. Evol.* **20**, 449–456. (doi:10.1016/j.tree.2005.05.008)
48. Couzin ID. 2009 Collective cognition in animal groups. *Trends Cogn. Sci.* **13**, 36–43. (doi:10.1016/j.tics.2008.10.002)
49. Dyer JRG, Johansson A, Helbing D, Couzin ID, Krause J. 2009 Leadership, consensus decision making and collective behaviour in humans. *Phil. Trans. R. Soc. B* **364**, 781–789. (doi:10.1098/rstb.2008.0233)
50. Kerth G. 2010 Group decision-making in animal societies. In *Animal behaviour: evolution and mechanisms* (ed. P Kappeler), pp. 241–265. Berlin, Germany: Springer. (doi:10.1007/978-3-642-02624-9_9)
51. Boyd R, Richerson PJ. 2009 Culture and the evolution of human cooperation. *Phil. Trans. R. Soc. B* **364**, 3281–3288. (doi:10.1098/rstb.2009.0134)
52. Tinbergen N. 1963 On aims and methods of ethology. *Z. Tierpsychol.* **20**, 410–433. (doi:10.1111/j.1439-0310.1963.tb01161.x)
53. Bateson P, Laland KN. 2013 Tinbergen's four questions: an appreciation and an update. *Trends Ecol. Evol.* **28**, 712–718. (doi:10.1016/j.tree.2013.09.013)
54. Couzin K. 2003 Self-organization and collective behavior in vertebrates. *Adv. Study Behav.* **32**, 1–75. (doi:10.1016/S0065-3454(03)01001-5)
55. Wilson EO. 1971 *The insect societies*. Cambridge, MA: Belknap Press of Harvard University Press.
56. Vittori K, Talbot G, Gautrais J, Fourcassié V, Araújo AFR, Theraulaz G. 2006 Path efficiency of ant foraging trails in an artificial network. *J. Theor. Biol.* **239**, 507–515. (doi:10.1016/j.jtbi.2005.08.017)
57. Jackson DE, Ratnieks FW. 2006 Communication in ants. *Curr. Biol.* **16**, R570–R574. (doi:10.1016/j.cub.2006.07.015)
58. Partridge BL, Pitcher T, Cullen JM, Wilson J. 1980 The three-dimensional structure of fish schools. *Behav. Ecol. Sociobiol.* **6**, 277–288. (doi:10.1007/BF00292770)
59. Parrish JK, Viscido SV, Grünbaum D. 2002 Self-organized fish schools: an examination of emergent properties. *Biol. Bull.* **202**, 296–305. (doi:10.2307/1543482)
60. Gueron S, Levin SA. 1993 Self-organization of front patterns in large wildebeest herds. *J. Theor. Biol.* **165**, 541–552. (doi:10.1006/jtbi.1993.1206)
61. Ben-Jacob E. 2008 Social behavior of bacteria: from physics to complex organization. *Eur. Phys. J. B* **65**, 315–322. (doi:10.1140/epjb/e2008-00222-x)
62. Shapiro JA. 1998 Thinking about bacterial populations as multicellular organisms. *Annu. Rev. Microbiol.* **52**, 81–104. (doi:10.1146/annurev.micro.52.1.81)
63. Lyon P. 2015 The cognitive cell: bacterial behavior reconsidered. *Front. Microbiol.* **6**, 264. (doi:10.3389/fmicb.2015.00264)
64. Moussaid M, Helbing D, Theraulaz G. 2011 How simple rules determine pedestrian behavior and crowd disasters. *Proc. Natl Acad. Sci. USA* **108**, 6884–6888. (doi:10.1073/pnas.1016507108)
65. Moussaid M, Helbing D, Garnier S, Johansson A, Combe M, Theraulaz G. 2009 Experimental study of the behavioural mechanisms underlying self-organization in human crowds. *Proc. R. Soc. B* **276**, 2755–2762. (doi:10.1098/rspb.2009.0405)
66. Falandays JB, Smaldino PE. 2022 The emergence of cultural attractors: how dynamic populations of learners achieve collective cognitive alignment. *Cogn. Sci.* **46**, e13183. (doi:10.1111/cogs.13183)
67. Dreyer T, Haluts A, Korman A, Gov N, Fonio E, Feinerman O. 2025 Comparing cooperative geometric puzzle solving in ants versus humans. *Proc. Natl Acad. Sci. USA* **122**, e2414274121. (doi:10.1073/pnas.2414274121)
68. von Frisch K. 1967 *The dance language and orientation of bees*. Cambridge, MA: Harvard University Press.
69. Biesmeijer JC, Seeley TD. 2005 The use of waggle dance information by honey bees throughout their foraging careers. *Behav. Ecol. Sociobiol.* **59**, 133–142. (doi:10.1007/s00265-005-0019-6)
70. Seeley T, Camazine S, Sneyd J. 1991 Collective decision-making in honey bees: how colonies choose among nectar sources. *Behav. Ecol. Sociobiol.* **28**, 277–290. (doi:10.1007/BF00175101)
71. Seeley TD. 2012 Progress in understanding how the waggle dance improves the foraging efficiency of honey bee colonies. In *Honeybee neurobiology and behavior: a tribute to Randolph Menzel* (eds CG Galizia, D Eisenhardt, M Giurfa), pp. 77–87. Dordrecht, The Netherlands: Springer Netherlands. (doi:10.1007/978-94-007-2099-2_7)
72. Wray MK, Klein BA, Seeley TD. 2012 Honey bees use social information in waggle dances more fully when foraging errors are more costly. *Behav. Ecol.* **23**, 125–131. (doi:10.1093/beheco/arr165)
73. Biro D, Sumpter DJT, Meade J, Guilford T. 2006 From compromise to leadership in pigeon homing. *Curr. Biol.* **16**, 2123–2128. (doi:10.1016/j.cub.2006.08.087)
74. Franks NR, Pratt SC, Mallon EB, Britton NF, Sumpter DJT. 2002 Information flow, opinion polling and collective intelligence in house-hunting social insects. *Phil. Trans. R. Soc. B* **357**, 1567–1583. (doi:10.1098/rstb.2002.1066)
75. Gilede M, Kissai A, Gutierrez B, Usui A, Sanabria F, Sasaki T. 2026 Individual vs. collective associative learning in ants. *Phil. Trans. R. Soc. B* **381**, 20240442. (doi:10.1098/rstb.20240442)
76. Smith JE *et al.* 2016 Leadership in mammalian societies: emergence, distribution, power, and payoff. *Trends Ecol. Evol.* **31**, 54–66. (doi:10.1016/j.tree.2015.09.013)
77. Garfield ZH, von Rueden C, Hagen EH. 2019 The evolutionary anthropology of political leadership. *Leadersh. Q.* **30**, 59–80. (doi:10.1016/j.leaqua.2018.09.001)
78. King AJ, Cowlshaw G. 2009 Leaders, followers, and group decision-making. *Commun. Integr. Biol.* **2**, 147–150. (doi:10.4161/cib.7562)
79. Krause J, Hoare D, Krause S, Hemelrijk CK, Rubenstein DI. 2000 Leadership in fish shoals. *Fish Fish.* **1**, 82–89. (doi:10.1111/j.1467-2979.2000.tb00001.x)
80. Radford AN. 2004 Vocal coordination of group movement by green woodhoopoes (*Phoeniculus purpureus*). *Ethology* **110**, 11–20. (doi:10.1046/j.1439-0310.2003.00943.x)
81. Strandburg-Peshkin A, Farine DR, Couzin ID, Crofoot MC. 2015 Shared decision-making drives collective movement in wild baboons. *Science* **348**, 1358–1361. (doi:10.1126/science.aaa5099)
82. Papageorgiou D, Farine DR. 2020 Shared decision-making allows subordinates to lead when dominants monopolize resources. *Sci. Adv.* **6**, eaba5881. (doi:10.1126/sciadv.aba5881)
83. Nagy M, Vársárhelyi G, Pettit B, Roberts-Mariani I, Vicssek T, Biro D. 2013 Context-dependent hierarchies in pigeons. *Proc. Natl Acad. Sci. USA* **110**, 13049–13054. (doi:10.1073/pnas.1305521110)
84. Couzin ID, Krause J, Franks NR, Levin SA. 2005 Effective leadership and decision-making in animal groups on the move. *Nature* **433**, 513–516. (doi:10.1038/nature03236)
85. Fischhoff IR, Sundaresan SR, Cordingley J, Larkin HM, Sellier MJ, Rubenstein DI. 2007 Social relationships and reproductive state influence leadership roles in movements of plains zebra, *Equus burchellii*. *Anim. Behav.* **73**, 825–831. (doi:10.1016/j.anbehav.2006.10.012)
86. Van Vugt M, von Rueden CR. 2020 From genes to minds to cultures: evolutionary approaches to leadership. *Leadersh. Q.* **31**, 101404. (doi:10.1016/j.leaqua.2020.101404)
87. Whiten A. 2021 The burgeoning reach of animal culture. *Science* **372**, eabe6514. (doi:10.1126/science.abe6514)

88. Perry S. 2003 Social conventions in wild white-faced capuchin monkeys: evidence for traditions in a neotropical primate. *Curr. Anthropol.* **44**, 241–268. (doi:10.1086/345825)
89. Perry S. 2011 Social traditions and social learning in capuchin monkeys (*Cebus*). *Phil. Trans. R. Soc. B* **366**, 988–996. (doi:10.1098/rstb.2010.0317)
90. Coelho CG, Falótico T, Izar P, Mannu M, Resende BD, Siqueira JO, Ottoni EB. 2015 Social learning strategies for nut-cracking by tufted capuchin monkeys (*Sapajus* spp.). *Anim. Cogn.* **18**, 911–919. (doi:10.1007/s10071-015-0861-5)
91. Garland EC, Goldizen AW, Rekdahl ML, Constantine R, Garrigue C, Hauser ND, Poole MM, Robbins J, Noad MJ. 2011 Dynamic horizontal cultural transmission of humpback whale song at the ocean basin scale. *Curr. Biol.* **21**, 687–691. (doi:10.1016/j.cub.2011.03.019)
92. Garland EC, Garrigue C, Noad MJ. 2022 When does cultural evolution become cumulative culture? A case study of humpback whale song. *Phil. Trans. R. Soc. B* **377**, 20200313. (doi:10.1098/rstb.2020.0313)
93. Allen JA, Garland EC, Dunlop RA, Noad MJ. 2018 Cultural revolutions reduce complexity in the songs of humpback whales. *Proc. R. Soc. B* **285**, 20182088. (doi:10.1098/rspb.2018.2088)
94. Sasaki T, Biro D. 2017 Cumulative culture can emerge from collective intelligence in animal groups. *Nat. Commun.* **8**, 15049. (doi:10.1038/ncomms15049)
95. Alem S, Perry CJ, Zhu X, Loukola OJ, Ingraham T, Sovik E, Chittka L. 2016 Associative mechanisms allow for social learning and cultural transmission of string pulling in an insect. *PLoS Biol.* **14**, e1002564. (doi:10.1371/journal.pbio.1002564)
96. Danchin E *et al.* 2018 Cultural flies: conformist social learning in fruitflies predicts long-lasting mate-choice traditions. *Science* **362**, 1025–1030. (doi:10.1126/science.aat1590)
97. Battesti M, Moreno C, Joly D, Mery F. 2012 Spread of social information and dynamics of social transmission within *Drosophila* groups. *Curr. Biol.* **22**, 309–313. (doi:10.1016/j.cub.2011.12.050)
98. Brooker J, van Leeuwen EJC, Clay Z. 2026 Social structure as a form of collective intelligence—a new framework. *Phil. Trans. R. Soc. B* **381**, 20240443. (doi:10.1098/rstb.20240443)
99. Boyd R, Richerson PJ. 1985 *Culture and the evolutionary process*. Chicago, IL: University of Chicago Press.
100. Aoki K, Feldman MW. 2014 Evolution of learning strategies in temporally and spatially variable environments: a review of theory. *Theor. Popul. Biol.* **91**, 3–19. (doi:10.1016/j.tpb.2013.10.004)
101. Tennie C, Call J, Tomasello M. 2009 Ratcheting up the ratchet: on the evolution of cumulative culture. *Phil. Trans. R. Soc. B* **364**, 2405–2415. (doi:10.1098/rstb.2009.0052)
102. Mesoudi A, Thornton A. 2018 What is cumulative cultural evolution? *Proc. R. Soc. B* **285**, 20180712. (doi:10.1098/rspb.2018.0712)
103. Dean LG, Vale GL, Laland KN, Flynn E, Kendal RL. 2014 Human cumulative culture: a comparative perspective. *Biol. Rev.* **89**, 284–301. (doi:10.1111/brv.12053)
104. Tomasello M, Call J. 2024 *Primate cognition*, pp. 157–213, 2nd edn. Oxford, UK: Oxford University Press. (doi:10.1093/oso/9780198910626.003.0004)
105. Claidière N, Smith K, Kirby S, Fagot J. 2014 Cultural evolution of systematically structured behaviour in a non-human primate. *Proc. R. Soc. B* **281**, 20141541. (doi:10.1098/rspb.2014.1541)
106. Jesmer BR *et al.* 2018 Is ungulate migration culturally transmitted? Evidence of social learning from translocated animals. *Science* **361**, 1023–1025. (doi:10.1126/science.aat0985)
107. Gunasekaram C *et al.* 2024 Population connectivity shapes the distribution and complexity of chimpanzee cumulative culture. *Science* **386**, 920–925. (doi:10.1126/science.adk3381)
108. Vinicius L, Gunasekaram C, Miglino A. 2026 Ultimate and proximate explanations for human cumulative culture and collective intelligence. *Phil. Trans. R. Soc. B* **381**, 20240446. (doi:10.1098/rstb20240446)
109. Anwarzai Z, Moser C, Dromiack H, Garg K, Ramos-Fernandez G. 2026 Collective intelligence as collective information processing. *Cognition* **270**, 106433. (doi:10.1016/j.cognition.2025.106433)
110. Rawlings B, Vale G, Legare C, Monfils MH, Proctor D, Brosnan S. 2026 Clever vermin? Collective intelligence in rats and roaches. *Phil. Trans. R. Soc. B* **381**, 20240441. (doi:10.1098/rstb20240441)
111. Smaldino PE. 2014 The cultural evolution of emergent group-level traits. *Behav. Brain Sci.* **37**, 243–254. (doi:10.1017/S0140525X13001544)
112. Warren E, Pilgrim C, Aellen M, Morford J, Herrmann E, Mann R, Biro D, Krupenye C. 2026 Chimpanzees spontaneously prepare for mutually-exclusive possibilities and collective context strengthens this behaviour. *Phil. Trans. R. Soc. B* **381**, 20240444. (doi:10.1098/rstb20240444)
113. Koomen R. 2026 Cooperative sustainability: a case for collective intelligence. *Phil. Trans. R. Soc. B* **381**, 20240445. doi:10.1098/rstb.2024.0445
114. Richerson PJ. 1998 The evolution of human ultra-sociality. In *Ideology, warfare, and indoctrinability* (eds I Eibl-Eibesfeldt, F Salter), pp. 71–96. New York, NY: Berghahn Books. (doi:10.2307/jj.7079921.9)
115. Campbell DT. 1983 The two distinct routes beyond kin selection to ultrasociality: implications for the humanities and social sciences. In *The nature of prosocial development: theories and strategies* (ed. DL Bridgeman), pp. 11–41. New York, NY: Academic Press.
116. Powers ST, van Schaik CP, Lehmann L. 2016 How institutions shaped the last major evolutionary transition to large-scale human societies. *Phil. Trans. R. Soc. B* **371**, 20150098. (doi:10.1098/rstb.2015.0098)
117. Henrich JP. 2016 *The secret of our success: how culture is driving human evolution, domesticating our species, and making us smarter*. Princeton, NJ: Princeton University Press.
118. Kaplan H, Hill K, Lancaster J, Hurtado AM. 2000 A theory of human life history evolution: diet, intelligence, and longevity. *Evol. Anthropol.* **9**, 156–185. (doi:10.1002/1520-6505(2000)9:43.0.CO;2-7)
119. Kaplan HS, Robson AJ. 2002 The emergence of humans: the coevolution of intelligence and longevity with intergenerational transfers. *Proc. Natl Acad. Sci. USA* **99**, 10221–10226. (doi:10.1073/pnas.152502899)
120. Burkart JM, Hrdy SB, Van Schaik CP. 2009 Cooperative breeding and human cognitive evolution. *Evol. Anthropol.* **18**, 175–186. (doi:10.1002/evan.20222)
121. Kramer KL. 2010 Cooperative breeding and its significance to the demographic success of humans. *Annu. Rev. Anthropol.* **39**, 417–436. (doi:10.1146/annurev.anthro.012809.105054)
122. Kaplan HS, Schniter E, Smith VL, Wilson BJ. 2012 Risk and the evolution of human exchange. *Proc. R. Soc. B* **279**, 2930–2935. (doi:10.1098/rspb.2011.2614)
123. Bird RB, Coddling BF. 2015 The sexual division of labor. In *Emerging trends in the social and behavioral sciences* (eds RA Scott, SM Kosslyn), pp. 1–16. Hoboken, NJ: Wiley. (doi:10.1002/9781118900772)
124. Taborsky M, Fewell JH, Gilles R, Taborsky B. 2025 Division of labour as key driver of social evolution. *Phil. Trans. R. Soc. B* **380**, 20230261. (doi:10.1098/rstb.2023.0261)
125. Bowles S, Gintis H. 2004 The evolution of strong reciprocity: cooperation in heterogeneous populations. *Theor. Popul. Biol.* **65**, 17–28. (doi:10.1016/j.tpb.2003.07.001)
126. Boyd R, Richerson PJ. 2022 Large-scale cooperation in small-scale foraging societies. *Evol. Anthropol.* **31**, 175–198. (doi:10.1002/evan.21944)
127. Vadavalli BD, Garfield Z, Glowacki L. 2026 Social structure shapes consensus decision-making norms in small-scale societies: an agent-based model perspective. *Phil. Trans. R. Soc. B* **381**, 20240449. (doi:10.1098/rstb20240449)
128. Holloway RL. 1981 Culture, symbols, and human brain evolution: a synthesis. *Dialect. Anthropol.* **5**, 287–303. (doi:10.1007/BF00246207)
129. MacWhinney B. 2005 Language evolution and human development. In *Origins of the social mind: evolutionary psychology and child development* (eds BJ Ellis, DF Bjorklund), pp. 383–410. New York, NY: Guilford Press.
130. Koymen B, Waddington O. 2026 Collaborative reasoning and problem solving in early childhood. *Phil. Trans. R. Soc. B* **381**, 20240447. (doi:10.1098/rstb20240447)

131. Boyd R, Richerson PJ, Henrich J. 2011 The cultural niche: why social learning is essential for human adaptation. *Proc. Natl Acad. Sci. USA* **108**, 10918–10925. (doi:10.1073/pnas.1100290108)
132. van Schaik CP, Burkart JM. 2011 Social learning and evolution: the cultural intelligence hypothesis. *Phil. Trans. R. Soc. B* **366**, 1008–1016. (doi:10.1098/rstb.2010.0304)
133. Kline MA. 2015 How to learn about teaching: an evolutionary framework for the study of teaching behavior in humans and other animals. *Behav. Brain Sci.* **38**, e31. (doi:10.1017/S0140525X14000090)
134. O'Madagain C, Tomasello M. 2022 Shared intentionality, reason-giving and the evolution of human culture. *Phil. Trans. R. Soc. B* **377**, 20200320. (doi:10.1098/rstb.2020.0320)
135. d'Errico F, Meneganzin A, Colagè I. 2026 Scaffolding minds: human collective intelligence through space, body and material symbols. *Phil. Trans. R. Soc. B* **381**, 20240448. (doi:10.1098/rstb.20240448)
136. Winters J, Charbonneau M. 2026 Modelling the emergence of open-ended cultural evolution. *Phil. Trans. R. Soc. B* **381**, 20240255. (doi:10.1098/rstb.20240255)
137. Fehr E, Fischbacher U. 2004 Social norms and human cooperation. *Trends Cogn. Sci.* **8**, 185–190. (doi:10.1016/j.tics.2004.02.007)
138. Cassar A, d'Adda G, Grosjean P. 2014 Institutional quality, culture, and norms of cooperation: evidence from behavioral field experiments. *J. Law Econ.* **57**, 821–863. (doi:10.1086/678331)
139. Gavrilits S, Richerson PJ. 2017 Collective action and the evolution of social norm internalization. *Proc. Natl Acad. Sci. USA* **114**, 6068–6073. (doi:10.1073/pnas.1703857114)
140. Sheehy-Skeffington J, Thomsen L. 2020 Egalitarianism: psychological and socio-ecological foundations. *Curr. Opin. Psychol.* **32**, 146–152. (doi:10.1016/j.copsyc.2019.08.014)
141. Borgerhoff Mulder M *et al.* 2009 Intergenerational wealth transmission and the dynamics of inequality in small-scale societies. *Science* **326**, 682–688. (doi:10.1126/science.1178336)
142. Gurven M *et al.* 2010 Domestication alone does not lead to inequality. *Curr. Anthropol.* **51**, 49–64. (doi:10.1086/648587)
143. Singh M, Glowacki L. 2022 Human social organization during the late Pleistocene: beyond the nomadic-egalitarian model. *Evol. Hum. Behav.* **43**, 418–431. (doi:10.1016/j.evolhumbehav.2022.07.003)
144. Boehm C. 1993 Egalitarian behavior and reverse dominance hierarchy. *Curr. Anthropol.* **34**, 227–254. (doi:10.1086/204166)
145. Venkataraman VV, Kraft TS. 2025 Consensus, cooperation and collective intelligence in foraging societies. *Hunter-Gatherer Res.* **12**, 1–42. (doi:10.3828/hgr.2026.9)
146. Glowacki L, von Rueden C. 2015 Leadership solves collective action problems in small-scale societies. *Phil. Trans. R. Soc. B* **370**, 20150010. (doi:10.1098/rstb.2015.0010)
147. El Aissati T, Goubraim G, Erut A, Servan-Schreiber E, Tetteh G, Legare C. 2026 Locals know more than they seem to: a new method for revealing collective understanding, tested in three African communities. *Phil. Trans. R. Soc. B* **381**, 20240453. (doi:10.1098/rstb.2024.0453)
148. Harris JA, Boyd R, Wood BM. 2021 The role of causal knowledge in the evolution of traditional technology. *Curr. Biol.* **31**, 1798–1803. (doi:10.1016/j.cub.2021.01.096)
149. Richerson PJ, Boyd R, Henrich J. 2010 Gene-culture coevolution in the age of genomics. *Proc. Natl Acad. Sci. USA* **107**, 8985–8992. (doi:10.1073/pnas.0914631107)
150. Perreault C. 2012 The pace of cultural evolution. *PLoS One* **7**, e45150. (doi:10.1371/journal.pone.0045150)
151. Smaldino PE *et al.* 2024 Information architectures: a framework for understanding socio-technical systems. *SocArXiv*. (doi:10.31235/osf.io/c7vrw)
152. Pateman C. 2012 Participatory democracy revisited. *Perspect. Polit.* **10**, 7–19. (doi:10.1017/S1537592711004877)
153. Cabannes Y. 2004 Participatory budgeting: a significant contribution to participatory democracy. *Environ. Urban.* **16**, 27–46. (doi:10.1177/095624780401600104)
154. Landemore H. 2015 Inclusive constitution-making: the Icelandic experiment. *J. Polit. Philos.* **23**, 166–191. (doi:10.1111/jopp.12032)
155. Farrell DM, Suiter J, Harris C. 2019 'Systematizing' constitutional deliberation: the 2016–18 citizens' assembly in Ireland. *Ir. Polit. Stud.* **34**, 113–123. (doi:10.1080/07907184.2018.1534832)
156. Fishkin JS. 2018 *Democracy when the people are thinking*. vol. 1. Oxford, UK: Oxford University Press. (doi:10.1093/oso/9780198820291.001.0001)
157. Landemore H. 2017 *Democratic reason: politics, collective intelligence, and the rule of the many*. Princeton, NJ: Princeton University Press.
158. Fujiwara T, Wantchekon L. 2013 Can informed public deliberation overcome clientelism? Experimental evidence from Benin. *Am. Econ. J.* **5**, 241–255. (doi:10.1257/app.5.4.241)
159. Gowers T, Nielsen M. 2009 Massively collaborative mathematics. *Nature* **461**, 879–881. (doi:10.1038/461879a)
160. Tao T, Croot E III, Helfgott H. 2012 Deterministic methods to find primes. *Math. Comput.* **81**, 1233–1246. (doi:10.1090/S0025-5718-2011-02542-1)
161. Polymath DHJ. 2019 Effective approximation of heat flow evolution of the Riemann ξ function, and a new upper bound for the de Bruijn–Newman constant. *Res. Math. Sci.* **6**, 31. (doi:10.1007/s40687-019-0193-1)
162. Horowitz S *et al.* 2016 Determining crystal structures through crowdsourcing and coursework. *Nat. Commun.* **7**, 12549. (doi:10.1038/ncomms12549)
163. Keasar C *et al.* 2018 An analysis and evaluation of the WeFold collaborative for protein structure prediction and its pipelines in CASP11 and CASP12. *Sci. Rep.* **8**, 9939. (doi:10.1038/s41598-018-26812-8)
164. Simmons BD *et al.* 2017 Galaxy Zoo: quantitative visual morphological classifications for 48 000 galaxies from CANDELS72. *Mon. Not. R. Astron. Soc.* **464**, 4420–4447. (doi:10.1093/mnras/stw2587)
165. Eisner NL *et al.* 2021 Planet Hunters TESS III: two transiting planets around the bright G dwarf HD 152843. *Mon. Not. R. Astron. Soc.* **505**, 1827–1840. (doi:10.1093/mnras/stab1253)
166. Papadakis S. 2023 MOOCs 2012–2022: an overview. *Adv. Mobile Learn. Educ. Res.* **3**, 682–693. (doi:10.25082/AMLER.2023.01.017)
167. Pykälä M, Dillion D, Galesic M. 2026 Heterogeneous learning strategies interact with social network structure and problem complexity to benefit collective search. *Phil. Trans. R. Soc. B* **381**, 20240450. (doi:10.1098/rstb.20240450)
168. Arrow KJ *et al.* 2008 The promise of prediction markets. *Science* **320**, 877–878. (doi:10.1126/science.1157679)
169. Dietrich F, List C. 2026 Collective intelligence through aggregation. *Phil. Trans. R. Soc. B* **381**, 20240454. (doi:10.1098/rstb.20240454)
170. Brinkmann L *et al.* 2023 Machine culture. *Nat. Hum. Behav.* **7**, 1855–1868. (doi:10.1038/s41562-023-01742-2)
171. Jeddi Y, Segovia-Martin J, Servan-Schreiber E. 2026 Crowdsourced versus LLM forecasting: evidence for the accuracy–correlation effect. *Phil. Trans. R. Soc. B* **381**, 20240456. (doi:10.1098/rstb.2024.0456)
172. Helbing D. 2013 Globally networked risks and how to respond. *Nature* **497**, 51–59. (doi:10.1038/nature12047)
173. Mulgan G. 2026 Global brains: the science and practice of collective intelligence at the level of whole systems. *Phil. Trans. R. Soc. B* **381**, 20240452. (doi:10.1098/rstb.20240452)
174. Moussaid M, Toyokawa W, Kurvers R. 2026 Asymmetrical social copying drives behavioral cascades following a shock event. *Phil. Trans. R. Soc. B* **381**, 20240451. (doi:10.1098/rstb.20240451)
175. Mulgan G. 2025 A theory of collective stupidity in organisations—and possible remedies. *Organ. Stud.* **46**, 1331–1335. (doi:10.1177/01708406251349313)
176. Sasaki T, Granovskiy B, Mann RP, Sumpter DJT, Pratt SC. 2013 Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proc. Natl Acad. Sci. USA* **110**, 13769–13773. (doi:10.1073/pnas.1304917110)
177. Schneirla TC. 1944 *A unique case of circular milling in ants, considered in relation to trail following and the general problem of orientation*. New York, NY: American Museum Novitates.
178. Halling A, Baekgaard M. 2024 Administrative burden in citizen–state interactions: a systematic literature review. *J. Public Adm. Res. Theory* **34**, 180–195. (doi:10.1093/jopart/muad023)

179. Heinrich CJ. 2016 The bite of administrative burden: a theoretical and empirical investigation. *J. Public Adm. Res. Theory* **26**, 403–420. (doi:10.1093/jopart/muv034)
180. Kaplan RM, Chambers DA, Glasgow RE. 2014 Big data and large sample size: a cautionary note on the potential for bias. *Clin. Transl. Sci.* **7**, 342–346. (doi:10.1111/cts.12178)
181. Plato. 2003 *The republic*, 2nd edn, reissued with new further reading. London, UK: Penguin Books.
182. Brennan J. 2017 *Against democracy*. Princeton, NJ: Princeton University Press.
183. Krause J, Ruxton GD, Krause S. 2010 Swarm intelligence in animals and humans. *Trends Ecol. Evol.* **25**, 28–34. (doi:10.1016/j.tree.2009.06.016)
184. Krause S, James R, Faria JJ, Ruxton GD, Krause J. 2011 Swarm intelligence in humans: diversity can trump ability. *Anim. Behav.* **81**, 941–948. (doi:10.1016/j.anbehav.2010.12.018)
185. Ladha KK. 1995 Information pooling through majority-rule voting: Condorcet's jury theorem with correlated votes. *J. Econ. Behav. Organ.* **26**, 353–372. (doi:10.1016/0167-2681(94)00068-P)
186. Bak-Coleman JB *et al.* 2021 Stewardship of global collective behavior. *Proc. Natl Acad. Sci. USA* **118**, e2025764118. (doi:10.1073/pnas.2025764118)