

Essay

Wise Adaptivity: How Collective Intelligence Can Benefit from System Dynamics and Vice Versa

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Abstract. This essay examines the relationship between system dynamics (SD) and collective intelligence (CI) through a bidirectional lens. System dynamics offers collective intelligence research three concrete methodological contributions: causal loop diagrams make the feedback structures underlying consensus formation explicit and manipulable; group model building (GMB) provides replicable participatory processes for integrating heterogeneous knowledge across organizational and community boundaries; and stock-and-flow modelling transforms collective intelligence from a momentary group property into a dynamic organizational feature. The essay then identifies three critical blind spots that collective intelligence research exposes within system dynamics: the Diversity Paradox, whereby GMB's consensus-building processes risk suppressing the cognitive heterogeneity on which robust collective judgement depends; the politics of knowledge aggregation, since mainstream SD practice treats power as external to model structure while CI research shows how social influence determines whether group processes produce wisdom or institutionalized bias; and the epistemological limits of structural reasoning, neglecting emergent phenomena that may be underrepresented by forcing plural, emergent processes into causal categories. These tensions are not problems to be resolved but a productive conceptual terrain for future work. The essay argues for wise adaptivity as a design aspiration: preserving cognitive diversity and political voice whilst building sufficient coordination for collective action.

Keywords. *Collective intelligence, system dynamics, group model building, diversity paradox, wise adaptivity*

Introduction

Collective intelligence (CI)—the emergent capacity of groups to solve problems, make decisions, and generate knowledge beyond individual capability (Malone & Bernstein, 2015; Woolley et al., 2010, though see Credé & Howardson, 2017, for a statistical critique)—has attracted considerable attention across disciplines, from organisational science to computational systems. The phenomenon rests on well-documented mechanisms: diversity of perspectives, feedback dynamics, information pooling, and adaptive coordination (Almaatouq et al., 2020). Yet while research identifies *what* conditions enable collective intelligence, substantially less attention has been paid to *how* organisations and policy communities can systematically cultivate these conditions in practice.

System dynamics (SD) offers a promising methodological foundation. Through causal loop diagrams (CLDs) and stock-and-flow models, system dynamics visualises feedback structures and simulates complex behaviour over time. As a participatory variant, group model building (GMB) brings diverse stakeholders together to co-construct shared mental models, explicitly surfacing feedback loops, delays, and accumulations that drive system behaviour. The method involves facilitated workshops where participants and modelling experts jointly develop visual

causal representations that synthesise tacit knowledge from multiple perspectives (Vennix, 1996; Andersen et al., 1997; Andersen et al., 2007). It has been applied successfully to organisational learning, public health interventions, and sustainability transitions. It would seem, therefore, to provide precisely the complementary concepts and tools that collective intelligence requires: a structured process for integrating heterogeneous knowledge, making feedback visible, and supporting coordinated action.

Yet system dynamics also faces limitations. Critics observe that models often treat actors as (boundedly) rational decision-makers, underplaying power dynamics, social norms, and political contestation. The epistemological commitment to identifiable causal structures may obscure genuinely emergent phenomena (e.g., organisational culture, innovation, trust) that resist simple reduction to feedback loops. Recent work on the “wisdom of crowds” reveals a troubling paradox: even mild social influence reduces the diversity of estimates without improving accuracy, thereby undermining the conditions under which aggregation produces collectively intelligent outcomes (Lorenz et al., 2011). Group model building, designed to foster shared understanding, risks homogenizing thinking precisely when cognitive diversity is most valuable.

This essay takes a bidirectional approach. First, it examines how system dynamics can enhance collective intelligence by providing feedback visualisation, participatory approach, and framework for organisational learning. Second, it identifies what system dynamics could learn from collective intelligence research: the Diversity Paradox, the role of power in knowledge aggregation, and the limits of structural reasoning when confronted with emergence. Based on this, it articulates three unresolved tensions—shared understanding versus cognitive diversity, operationalisation versus power, structure versus emergence—that represent productive avenues for future work. The aim is not to resolve these tensions but to establish a conceptual terrain where subsequent research can develop more integrated approaches. The underlying aspiration is what this essay calls *wise adaptivity*: the capacity to preserve cognitive diversity and political voice while still coordinating collective action. Designing for wise adaptivity means accepting that consensus, accuracy, and alignment each have a place, and learning when each should take precedence.

System Dynamics as Methodological Basis for Collective Intelligence Research

System dynamics offers collective intelligence research three concrete methodological contributions: feedback visualisation, participatory knowledge integration, and modelling of organisational learning over time.

A. Feedback Visualisation and Emergent Consensus

Recent work on collective decision-making reveals that consensus formation requires more than pairwise communication between individuals. When groups must choose between equally valid options—a scenario termed “symmetry breaking”—pairwise interactions alone often lead to deadlock. Higher-order interactions, in which groups of three or more individuals simultaneously influence one another, are essential for overcoming this stalemate and enabling the system to reach consensus. Autonomous behaviour, in which individuals independently explore options, combined with group-level social recruitment, creates the conditions for collective decision-making to succeed (March-Pons et al., 2025).

Causal loop diagrams (CLDs) make these feedback structures explicit and visible. CLDs map variables and their causal relationships using simple conventions (arrows with positive or

negative polarity) that non-technical stakeholders can understand, identifying reinforcing and balancing feedback loops and revealing how delays shape system behaviour (Lane, 2008; Sterman, 2000). Yet their intuitive simplicity can mask ambiguities in causation, and their visual parsimony may obscure the dynamic complexity that stock-and-flow diagrams capture (Richardson, 1997; Lane, 2008).

In the context of collective decision-making, a CLD renders visible the structural mechanisms necessary for consensus, where individual exploration generates diversity and social interactions amplify commitment to emerging options. This visualisation is not prescriptive about *what* groups should decide; rather, it clarifies *how* their communication and interaction structures must evolve to enable collective intelligence to emerge.

B. Group Model Building as Participatory Intelligence

Group model building (GMB) embodies collective intelligence in practice. GMB brings together diverse stakeholders—from different disciplines, departments, or communities—to co-construct a shared mental model through iterative refinement of causal loop diagrams (Vennix, 1996). The process is facilitated by trained modelling experts who translate participants' tacit knowledge, experience, and intuitive understanding into explicit visual causal structures.

The participatory dimension is crucial. Each participant brings heterogeneous (experiential, technical, political) knowledge accumulated through different roles and perspectives within the system under study. Rather than a single expert synthesising this knowledge into a model, GMB creates a structured dialogue in which diverse stakeholders negotiate and integrate their understandings through clearly differentiated facilitation roles (Richardson & Andersen, 1995). The resulting CLD becomes a boundary object: an artefact that simultaneously inhabits multiple “worlds” of disciplinary or professional knowledge, adapting to local needs whilst remaining sufficiently robust to coordinate across differences (Lee, 2007).

Hovmand's (2014) community-based system dynamics (CBSD) framework extends GMB beyond organisational settings to engage marginalised communities—including those affected by structural racism, childhood obesity, and educational inequity—as active knowledge producers rather than passive informants. CBSD emphasises moving participation along a continuum from passive information source to community mobilisation and action. Documented ‘scripts’ (i.e., structured small-group exercises for knowledge elicitation and model conceptualisation) make this process replicable and accessible to practitioners in community settings (Hovmand et al., 2012).

Empirical studies demonstrate that GMB generates learning outcomes beyond the model itself. Participants report shifts in mental models, improved understanding of systemic interdependencies, and increased trust and idea-sharing across previously siloed groups (Cruden et al., 2024). This process of collective learning is a hallmark of organisational intelligence development (Scott et al., 2016).

Systematic reviews of GMB outcomes provide robust evidence for these claims. Rouwette et al.'s (2002) meta-analysis of 107 GMB cases found consistent evidence of increased insight, consensus, and communication quality among participants. Later work demonstrated that GMB changes not only participants' cognitive understanding but also their attitudes, subjective norms, and behavioural intentions—suggesting that the method operates as a form of ‘modelling as persuasion’ that reshapes both mental models and motivation for action (Rouwette et al., 2011). This body of evidence establishes GMB as more than a technical modelling exercise; it is a socio-technical intervention that transforms how stakeholders understand and act within complex systems.

Recent methodological innovations have expanded GMB's scope and reflexivity. Online GMB adaptations, developed during and after the COVID-19 pandemic, have democratised access to participatory modelling while maintaining facilitation quality (Smeekes et al., 2023). Cultural adaptations in non-Western contexts have tailored GMB to diverse epistemological traditions, addressing power asymmetries between Global North methodologies and local knowledge systems (Li et al., 2023). Spatial group model building (SGMB) now integrates geographic information systems with causal mapping, enabling place-based analysis that acknowledges how spatial context shapes system dynamics (Rich et al., 2021). Participants gain not only intellectual understanding but also adaptive capacity: a deeper sense of how to navigate complexity in their own contexts.

C. Organisational Learning Through Dynamic Feedback

While individual learning may occur in moments, organisational learning likely unfolds over time. System dynamics provides this temporal dimension by modelling how individual cognition and action connect to organisational structures, routines, and institutionalised knowledge. The field distinguishes between single-loop learning (actors adjust behaviour in response to feedback) and double-loop learning (actors revise the underlying assumptions and mental models that guide behaviour; Argyris & Schön, 1978). System dynamics reveals how organisational design—stocks and flows of people, information, and resources—either supports or undermines both forms of learning.

Consider a simple feedback structure: individuals acquire knowledge through experience, which is codified and transmitted to new entrants, whose refined experience then circulates back into the knowledge base, establishing a reinforcing learning loop. However, time lags between observation, implementation, and retraining can interrupt this loop, causing learning to stall. Information silos create balancing loops that limit organisational intelligence to local pockets of competence.

Published models of organisational capability traps illustrate these dynamics. Repenning and Sterman (2001) show how short-term performance pressures create a balancing loop that systematically diverts resources from learning investments, causing organisations to substitute 'working harder' for 'working smarter'. This pattern can be seen as eroding collective intelligence over time.

System dynamics makes these temporal and structural dynamics explicit. Moreover, by coupling individual learning (how participants shift mental models) with organisational structures (how institutions preserve and transmit knowledge), SD transforms collective intelligence from a static property—"how wise is this group today?"—into a dynamic property: "does the organisation preserve and build upon its collective learning over time, or does it erode?"

What System Dynamics Could Learn from Collective Intelligence

Collective intelligence research can help to address three critical blind spots in system dynamics: the Diversity Paradox inherent in consensus-building, the political dimensions of knowledge aggregation, and the epistemological limits of structural reasoning when encountering genuine emergence.

A. The Diversity Paradox: Consensus as Threat to Wisdom

In a series of estimation experiments, Lorenz et al. (2011) repeatedly presented participants with the same factual questions, each time revealing the average of others' answers. A straightforward prediction would be that the additional information improves accuracy. It did not. Instead, three mechanisms combined to degrade collective performance: social influence narrowed the spread of estimates without shifting the group closer to the truth; the range of answers shrank until the correct value lay outside it; and participants grew more confident even as they grew less accurate. The result was a false consensus systematically worse than the uncorrelated guesses it replaced.

This finding sharpens a classical insight. Since Galton's (1907) observation that the median guess of a county-fair crowd landed remarkably close to the true weight of an ox, researchers have understood that aggregating independent judgments can cancel individual errors. The key condition is independence—or, more precisely, diversity of error. Lorenz et al. demonstrate how easily ordinary social interaction erodes that diversity, even when participants have no incentive to conform.

The picture is not entirely bleak, however. Almaatouq et al. (2020) demonstrate that when social networks possess plasticity (i.e., allowing individuals to adjust whom they attend to based on feedback about accuracy), collective estimates can surpass even the best individual. The critical variable is not whether social influence occurs, but whether the network structure adapts to amplify accurate contributions. This finding is directly relevant to GMB: it suggests that the design of interaction protocols during workshops, not merely their content, determines whether convergence enhances or undermines collective wisdom.

GMB is explicitly designed to foster *shared understanding*—to move stakeholders from disagreement towards alignment. Yet if the wisdom-of-crowds literature is correct, this convergence process may inadvertently sacrifice the cognitive diversity necessary for robust collective judgement. Stakeholders who begin with heterogeneous mental models and divergent causal assumptions may, through the process of building shared understanding, arrive at a consensus model that is less accurate and less able to cope with novel circumstances than their original diversity would have permitted.

Work on diversity in complex systems sharpens why this loss matters. Page (2007) argues that groups with diverse perspectives, heuristics, and predictive models can outperform homogeneous groups even when the latter contain more individually skilled members; diversity functions as a resource that allows exploration of a larger solution space. Smaldino et al. (2024) extend this argument by showing that maintaining transient diversity in group problem-solving—allowing different approaches to coexist and be winnowed over time—improves collective performance across a wide range of tasks. Taken together, these findings imply that the heterogeneity GMB risks suppressing is not a complication to be managed but a primary engine of collective intelligence.

In light of this tension, several procedural responses have been proposed. Research on minority dissent and team innovation highlights the value of structured dissent protocols and participatory decision-making arrangements that protect divergent views while groups converge on action (De Dreu & West, 2001). Recent participatory modelling work has begun to operationalise such mechanisms in SD contexts: multi-model approaches deliberately construct alternative causal structures to represent competing stakeholder framings rather than forcing premature synthesis into a single diagram (Deutsch et al., 2024), and group model building with adolescents on obesity has used explicit stages for surfacing and preserving heterogeneous mental models before integration (Savona et al., 2023). These examples remain

exceptions rather than standard practice, but they indicate concrete design choices through which GMB could move from consensus-seeking towards diversity-preserving coordination.

This tension has deep methodological roots. Zagonel (2024; originally 2007) reveals a fundamental dichotomy in system dynamics practice between ‘microworlds’—models that aim to accurately represent reality—and ‘boundary objects’—models that serve as transitional artefacts facilitating socially constructed alignment among stakeholders. Traditional SD emphasises parsimony and correct solutions (microworlds), while GMB leans toward boundary objects that encompass diverse stakeholder views, even at the cost of parsimony. The Diversity Paradox emerges precisely from this unresolved methodological duality. GMB practice has not yet developed principles for determining when to prioritize microworld accuracy (preserving diversity) versus boundary-object alignment (fostering consensus). From a CI perspective, the unanswered question is whether the diversity that groups begin with (i.e., before any facilitator intervenes) can be treated as a resource to be strategically preserved rather than a problem to be resolved.

B. Power Dynamics and the Politics of Knowledge Aggregation

Whose causal story ends up in the model? In any GMB workshop, some participants speak fluently in the language of feedback loops; others struggle to translate lived experience into variables and arrows. A senior administrator’s framing may carry institutional weight that a frontline worker’s testimony cannot match. The question is not whether power shapes the modelling process—it plainly does—but whether the methodology acknowledges this or treats it as exogenous to its own design.

System dynamics, as conventionally practised, tends toward the latter. Models represent stakeholder interests as preferences (inputs to a decision rule) and explain policy resistance as actors protecting those preferences. Power, in this framing, remains outside the model: it shapes behaviour around the causal structure but does not enter the structure itself. Collective intelligence research unsettles this separation. Becker et al. (2017) show that whether social influence improves or degrades collective wisdom depends entirely on how the system allocates “social power”: the relative weight given to different individuals’ judgements. If weight tracks accuracy, influence helps; if it tracks status or assertiveness, it harms.

Group model building, for all its participatory intent, is not immune to these power dynamics. The process of translating stakeholders’ tacit knowledge into explicit causal structure necessarily privileges certain types of knowledge (structural and quantifiable) whilst marginalising others (experiential, narrative, embodied). Stakeholders differ in their ability to articulate their knowledge in causal-loop language. Some possess rhetorical facility or organisational authority that allows their framings to dominate model development; others lack a voice. The “diversity” within the modelling group may be nominal—demographic variety masking underlying consensus imposed through power—rather than genuine cognitive heterogeneity. Moreover, the balance of power shifts across phases: a community member may lack authority in technical discussions but hold critical legitimacy during implementation, while a senior administrator who dominates model structure may face resistance from frontline staff during deployment.

The epistemic asymmetry runs deeper than voice. GMB’s representational grammar—variables, arrows, polarities—presupposes an analytic epistemology that decomposes wholes into causally related parts. Knowledge traditions grounded in relational, narrative, or embodied ways of knowing may resist this translation entirely, not because participants lack the ability to articulate their understanding, but because the method’s formal language cannot accommodate it. Frerichs et al. (2016) encountered precisely this when applying Critical Race Theory to GMB in a community violence project: standard variable-elicitation scripts proved

inadequate for participants whose knowledge was rooted in lived experience and racial socialisation, requiring replacement with vignette-based, narrative facilitation guides from which causal loop diagrams could emerge organically. Cultural adaptations of GMB in non-Western contexts (Li et al., 2023) have begun to address related concerns, but the fundamental question remains open: whether causal-loop language can serve as a genuinely inclusive medium for collective intelligence, or whether it systematically filters out ways of knowing that do not decompose into variables and arrows.

Critical systems thinking offers a theoretical foundation for this audit. Midgley's concept of boundary critique (Midgley et al., 1998; Midgley, 2000) demonstrates that every system definition involves value-laden judgements about inclusion and exclusion, and that elements in the 'marginal zone' between competing boundary definitions tend to be systematically devalued. In a GMB context, boundary critique would ask: whose lived experience falls within the system boundary drawn by the facilitator's initial framing? Whose falls outside? And how do those boundary choices predetermine the causal structure that emerges? Jackson's (2019) Critical Systems Practice extends this logic to methodological choice, arguing that different problem situations—characterised by varying levels of complexity and stakeholder conflict—require fundamentally different systems approaches rather than a single universal methodology. This provides a principled basis for the methodological pluralism that this essay advocates.

Hovmand's (2014) framework explicitly centres community members—particularly those most affected by systemic inequities—as expert knowledge holders whose perspectives must shape model structure, rather than merely as stakeholders whose buy-in is needed. CBSD applications to structural racism, for example, use group model building to create causal loop diagrams that emerge from communities' lived experiences rather than imposing academic or institutional framings (Hovmand, 2014).

Recent participatory systems dynamics research builds on this foundation through reflexive facilitation practices that surface whose knowledge is privileged, incorporate community-based participatory principles that redistribute decision-making authority, and employ 'social ecology of power' frameworks to audit power dynamics across micro (individual), meso (group), and macro (institutional) levels (Decker & Wendel, 2023; Egid et al., 2021). Recent adaptations of GMB for mental healthcare settings further demonstrate this trajectory, employing participatory co-design and 'radical openness' protocols that make methodological decisions transparent and contestable by community partners (Forrester-Bowling et al., 2025). While these innovations remain outside mainstream GMB practice, they demonstrate that the methodology can evolve to incorporate structural critique of its own processes. The collective intelligence implication is direct: unless the weighting of contributions in the modelling process tracks the quality of knowledge rather than the status of its holder, the result is not collective intelligence, but institutionalised bias dressed in participatory clothing.

C. Emergence Beyond Structure: Epistemological Limits

Collective intelligence is itself an emergent phenomenon arising from higher-order interactions, autonomous behaviour, and cognitive diversity, and cannot be reduced to individual-level properties (March-Pons et al., 2025; Hoel et al., 2013). This creates a direct tension with system dynamics' commitment to structural reasoning. The methods implicitly applied to model collective intelligence may, paradoxically, undermine the very emergence they seek to capture: by forcing plural, emergent processes into predetermined causal categories of variables and arrows, SD risks eliminating precisely the properties that make collective intelligence collectively intelligent.

System dynamics is built on a different epistemological wager: that complex behaviour arises from identifiable feedback structures, and that making those structures explicit through CLDs and stock-and-flow models enables practitioners to understand and, in some cases, predict system behaviour (Forrester, 1961). This wager has paid off across domains from supply chain management to public health. But it sits uneasily with phenomena whose essential character lies precisely in their resistance to structural decomposition.

System dynamics approaches these phenomena through structural reduction: culture is modelled as a stock-and-flow system, and trust is modelled as a feedback loop that affects information sharing. Yet this translation may lose essential features. The emergent properties (e.g., culture, trust) depend on meanings, narratives, and social recognition that cannot be fully captured in structural form. Modelling emergence solely through causal structures risks reinstating the very reductionism that the concept of emergence was meant to challenge (Christen & Franklin, 2005).

This is not a critique of system dynamics as a methodology, but rather a recognition of its epistemological boundaries. This recognition is growing within the SD community. A 2024 special issue of *System Dynamics Review* on ‘Qualitative Aspects of System Dynamics Modeling’ demonstrates that qualitative and quantitative SD serve complementary but distinct purposes, and that methodological pluralism can preserve emergent properties that structural reduction alone cannot capture (Stave et al., 2024).

Critical Tensions and Conclusion

System dynamics brings three concrete assets to collective intelligence research. First, causal loop diagrams make the feedback structures underlying consensus formation visible and manipulable, allowing groups not only to reach collective decisions but to inspect and redesign the interaction architectures through which those decisions emerge (Lane, 2008; March-Pons et al., 2025). Second, group model building operationalises collective intelligence as a practice: it provides facilitated, replicable processes for integrating heterogeneous knowledge, surfacing tacit assumptions, and building shared understanding across organisational and community boundaries (Vennix, 1996; Rouwette et al., 2011). Third, system dynamics transforms collective intelligence from a momentary property of groups into a dynamic one—modelling how organisations accumulate, transmit, and erode collective knowledge over time, and diagnosing the structural conditions under which learning loops either self-reinforce or collapse (Argyris & Schön, 1978; Repenning & Sterman, 2001). Together, these contributions suggest that system dynamics is not merely compatible with collective intelligence research but provides a methodological basis that collective intelligence research has not yet fully drawn upon.

Three fundamental tensions emerge from integrating system dynamics and collective intelligence research. Rather than problems to solve, these represent productive questions that should guide future work.

1. **Shared Understanding versus Cognitive Diversity.** Group model building is designed to foster shared understanding, yet the wisdom-of-crowds literature demonstrates that convergence processes can sacrifice the cognitive diversity necessary for robust collective judgement. The microworld/boundary-object duality (Zagonel, 2024) reveals that this tension is embedded in GMB’s methodological foundations. Structured dissent protocols, multi-model approaches, and diversity-preserving practices offer promising but still provisional responses.
2. **Operationalisation versus Power.** Power shapes what counts as causal knowledge, yet mainstream SD practice treats power as external to modelling. Community-based

system dynamics (Hovmand, 2014) and reflexive facilitation practices demonstrate that the methodology can evolve to incorporate structural critique, but these innovations remain outside standard practice.

3. Structure versus Emergence. System dynamics' epistemological commitment to identifiable feedback structures may constrain understanding of genuinely emergent phenomena. Methodological pluralism—integrating SD with agent-based modelling, network analysis, qualitative methods, and other complementary approaches—is necessary for phenomena where emergence is fundamental and irreducible.

The promise of collective intelligence lies not in perfect consensus or flawless judgement, but in wise adaptivity: the capacity to preserve cognitive diversity and political voice whilst building sufficient coordination for collective action. In practice, wise adaptivity might take the form of a GMB process that begins with individually elicited causal maps, preserves competing structures as named scenarios rather than merging them prematurely, and converges only on shared action commitments—leaving the causal disagreements visible and available for future re-evaluation.

The integration of the two literatures (system dynamics and collective intelligence) does not require either field to abandon its core commitments, but rather to recognise boundaries and develop complementary methods. Future work should develop approaches in which these methodologies inform and constrain one another, including AI-mediated interventions. Such approaches could yield more robust frameworks for designing systems in which collective intelligence actually emerges and endures.

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