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## **A Systems Dynamics Approach to Translating Knowledge into Community Empowerment through Cooperative Extension**

### **Abstract**

Cooperative Extension systems demonstrate proficiency in generating and disseminating information but face increasing demands to demonstrate measurable community impact beyond knowledge delivery. While the logic model has been widely adopted as a foundational framework for program planning and evaluation, its inherent linearity is structurally incompatible with the feedback loops and interactions that define socio-economic-ecological systems, thus constraining both its diagnostic utility and its predictive capacity. To address this limitation, this study introduces data → information → knowledge → wisdom → empowerment cycle enabled by ethics, trust, organization, and living labs as a systems dynamics approach. This model operationalizes community empowerment—defined as a community's demonstrated capacity for effective, intentional collective action that enhances socio-economic-ecological system stability—as the ultimate measurable impact. Data, information, knowledge, wisdom, and empowerment are conceptualized as state variables (amounts of change), while their transformations are processes (rates of change) managed through specific Cooperative Extension activities. This framework enables Cooperative Extension practitioners to diagnose bottlenecks in (cognitive, social, institutional, and adaptive) capacity development, predict intervention outcomes, optimize resource allocation, and trace community empowerment to enhanced socio-economic-ecological system stability.

**Abbreviations:** CE, Cooperative Extension; D→E, data → information → knowledge→wisdom→empowerment; DETOLL, data → information → knowledge→wisdom→empowerment cycle enabled by ethics, trust, organization, and living labs; DIKW, data→information→knowledge→wisdom; ETOLL, ethics-trust-organization within living labs; PFAS, per- and polyfluoroalkyl substances.

**Keywords:** socio-economic-ecological systems, DIKW model, living lab, program evaluation, adaptive management, systems dynamics, capacity building.

## Introduction

### The logic model paradox

For decades, the logic model has served as the cornerstone framework for program planning and evaluation within Cooperative Extension, providing a structured approach to articulating program theory and ensuring accountability (Taylor-Powell and Henert, 2008; Rennekamp and Engle, 2008). However, its linear architecture—inputs to outputs to outcomes—cannot model the nonlinear, feedback-rich dynamics of socio-economic-ecological systems (Arnold, 2015; Cabrera and Cabrera, 2015). This incompatibility limits its ability to explain how educational activities lead to sustained community empowerment. Evaluations across multiple continents reveal that Extension systems effectively disseminate information and knowledge but struggle to demonstrate causal linkages to improved resilience (Rajalahti and Swanson, 2010; Kennedy et al., 2025; Nin-Pratt and Stads, 2023). The central challenge is not knowledge delivery but the evidence-based translation of knowledge into demonstrable community empowerment.

### Knowledge gaps and study rationale

Despite widespread recognition of these limitations (Klerkx et al., 2010; Wigboldus et al., 2016), existing frameworks fail to: (1) operationalize the data-to-empowerment pathway as a dynamic system with measurable state and rate variables; (2) integrate

governance mechanisms (ethics, trust, and organization) as core enablers; and (3) provide validation environments for adaptive management. Recent advances in Agricultural Innovation Systems thinking emphasize enabling institutions (World Bank, 2012; Turner et al., 2016), while systems dynamics offers tools for managing feedback loops (Sterman, 2002; Meadows, 2008). However, no framework synthesizes these approaches for Extension contexts to diagnose bottlenecks, predict outcomes, and optimize pathways to community empowerment.

This study addresses this critical gap by introducing the conceptual model of data→information→knowledge→wisdom→empowerment cycle enabled by ethics, trust, organization, and living labs (DETOLL), which may advance Extension science in three fundamental ways. First, it reconceptualizes the knowledge-to-action pathway as a cycle with feedback loops. Second, it operationalizes ethics, trust, and organization mechanisms and validation environments (living labs) as quantifiable enablers whose strength directly predicts process success. Third, it provides a diagnostic and predictive tool to identify specific bottlenecks in the data→empowerment cycle, forecast outcomes, and optimize resource allocation. These innovations fill a critical methodological void, transitioning the field from outcome documentation to mechanism-based Extension program design and adaptive management.

### **Framework innovation and study objectives**

This study introduces the DETOLL model by extending the data → information →knowledge→wisdom (DIKW) hierarchy (Ackoff, 1989), which has been critiqued for operational ambiguity in its transitions (Rowley, 2007; Frické, 2009). Our approach introduces key novelties by;

(1) expanding the DIKW hierarchy to a dynamic data→empowerment cycle, defining 'empowerment' as a community's demonstrated capacity for collective action that enhances socio-economic-ecological system stability.

(2) treating each element as a measurable state variable and transitions as rate processes, actions, and feedback loops manageable by Extension, through a systems dynamics lens (Sterman, 2002; Pruyt, 2013).

(3) introducing ETOLL as the mechanisms that enable or constrain these processes; and

(4) integrating living labs as validation environments for iterative learning (Bergvall-Kåreborn et al., 2009; Schuurman et al., 2016).

The study objectives were to: (1) develop operational definitions for DETOLL components grounded in Extension practice; (2) propose measurable metrics for state variables and Extension activity-manageable processes; (3) demonstrate its applicability through diverse case study analyses; and (4) establish a research agenda for empirical validation.

### **Socio-economic-ecological system stability as the ultimate goal**

Socio-economic-ecological system stability is characterized by two complementary properties: resistance (the ability to absorb disturbance) and resilience (the capacity to adapt and reorganize) (Holling, 1973; Folke, 2006; Walker et al., 2004). Community empowerment manifests this stability. The model hypothesizes that achieving empowerment requires progress along the data→empowerment cycle, strengthened ETOLL enablers, and continuous feedback-driven adaptation.

## **Conceptual Development**

### **Theoretical foundation**

DETOLL synthesizes five theoretical domains: (1) information science and knowledge management (Ackoff, 1989; Rowley, 2007); (2) systems dynamics and complexity theory (Sterman, 2002; Meadows, 2008); (3) participatory innovation and co-creation

methodologies (Bergvall-Kåreborn et al., 2009; Schuurman et al., 2016); (4) Agricultural Innovation Systems thinking (World Bank, 2012; Klerkx et al., 2012); and (5) social capital theory (Putnam, 2000; Coleman, 1988). Comparative analyses of global Extension initiatives show that programs focusing solely on knowledge transfer while neglecting system-dynamics quantification and enablers exhibit reduced adoption (Anderson and Feder, 2004; Kithi et al., 2023; Ragasa et al., 2016). Success stories (e.g., Farmer Field Schools in Southeast Asia) highlight investment in trust-building and ethical engagement (Kithi et al., 2023; Waddington et al., 2014). Conversely, many technology-transfer programs fail due to inattention to local organizational capacity or ethical misalignment (Rajalahti and Swanson, 2010). A systematic review of 127 Extension programs across 34 countries (Nin-Pratt and Stads, 2023) found systemic over-investment in data and information and under-investment in wisdom and empowerment. DETOLL models the entire process as a cyclical dynamic system (Figure 1).

### **Operational systems-dynamics architecture**

Figure 1 illustrates the DETOLL architecture. The data→empowerment components are state variables (*i.e.*, accumulated quantities and qualities). Their transformations are rates of change (*i.e.*, processes and actions) manageable by Extension as follows:

- data→information:** Organizing, processing, contextualizing, disseminating;
- information→knowledge:** Synthesizing, validating, integrating, disseminating;
- knowledge→wisdom:** Contextualizing, demonstrating, mentoring, communicating;
- wisdom→empowerment:** Mobilizing, coordinating, advocating, sustaining; and
- empowerment→data** is a reinforcing feedback loop where empowered communities generate new data through innovation, monitoring, documentation, and sharing, continuously enriching the system's informational foundation.

Trust lowers information-sharing transaction costs and accelerates integration and synthesis; organization provides the infrastructure and facilitation capacity that enables transformations; and ethics ensures value alignment and equitable benefit distribution,

sustaining long-term engagement. The system is tested and refined within a living lab that provides real-time feedback, enabling the diagnosis of how the data→empowerment cycle is translated into empowerment to address issues with socio-economic-ecological system stability.

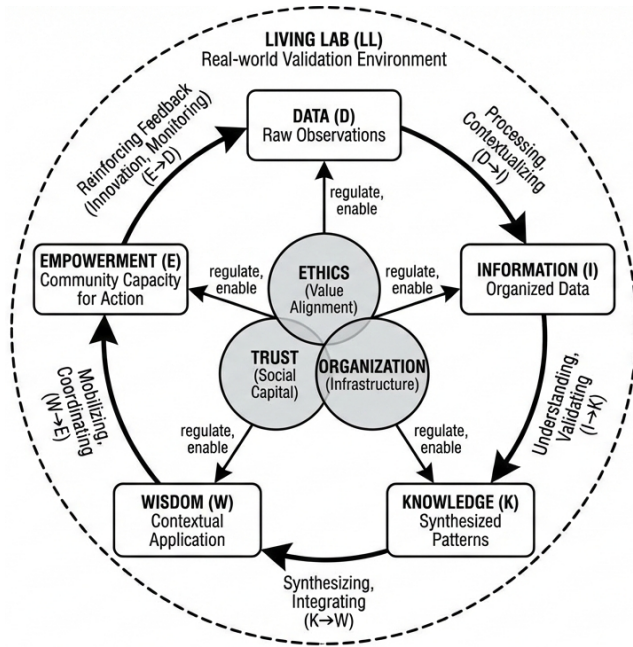


Figure 1. A systems dynamics framework of DETOLL cycle. Rectangles/circles are state variables (amounts of change); arrows are transformation processes (rates of change) and feedback loops managed by Extension; and living labs are the validation environment.

### Operational definitions

Table 1 presents operational definitions for all DETOLL components.

Table 1. Operational definitions of DETOLL cycle.

Component	Definition	Extension Context Example	Measurability
Data	Raw, unprocessed measurements & observations	Soil test values, yield counts, farm survey responses	Quality, quantity, type, spatiotemporal coverage
Information	Data organized, processed & contextualized to convey meaning	Map of soil nutrient deficiency, market price bulletin	Accessibility, timeliness, relevance
Knowledge	The synthesis of information into understanding of patterns, principles & strategies	Biological mechanism by which cover crops fix nitrogen	Comprehension depth, retention, transferability
Wisdom	The application of knowledge within specific contexts, informed by ethical judgment & trade-off analysis	Selecting leguminous species suitable for local soil, climate & farm economics	Decision quality, adaptive capacity, contextual fit
Empowerment	A community's capacity for effective, collective action that enhances socio-economic-ecological system stability	Farmers forming a cooperative to advocate for watershed-level conservation policies	Collective action frequency, policy influence, innovation emergence, sustained best practice adoption
Ethics	The process of ensuring moral alignment & equitable distribution of benefits and risks across all data→empowerment stages	Inclusive stakeholder engagement, transparent risk communication	Equity audits, value alignment surveys, fairness indices
Trust	The process of building and maintaining social capital & credibility that underpins collaboration & knowledge co-creation	Longitudinal educator-community relationships, peer networks	Trust scale scores, collaboration frequency, information-sharing patterns

Component	Definition	Extension Context Example	Measurability
Organization	The process of developing structural, procedural & partnership capacities necessary to support the data→empowerment cycle	Multi-stakeholder partnerships, technical infrastructure, facilitation capacity	Partnership functionality, resource adequacy, institutional capacity indices
Living lab	Real-world, user-centric innovation environment enabling iterative testing and co-creation	Community-university research partnerships, on-farm participatory trials	Stakeholder diversity, iteration frequency, co-creation outputs, scalability potential

## Systems dynamics perspective on capacity building

DETOLL conceptualizes empowerment as the multiplicative product of four interdependent capacities: cognitive (*e.g.*, knowledge and skills), social (*e.g.*, networks and trust), institutional (*e.g.*, procedures and governance), and adaptive (*e.g.*, ability to enhance resistance and resilience). The data→empowerment cycle builds cognitive and adaptive capacity. ETOLL enablers build social and institutional capacity: Trust builds social capital, organization builds institutional infrastructure, and ethics ensures equitable institutional governance. Living labs integrate, test, and refine these capacity-building processes.

Transformation rates depend on (1) the intensity and quality of specific Extension activities and (2) strength of ETOLL enablers (moderators or multipliers). This creates nonlinear dynamics where small yet strategic investments in ETOLL can produce large increases in transformation rates, representing key leverage points in the socio-economic-ecological systems (Meadows, 2015). The empowerment→data feedback loop empowers communities to generate new, context-rich data, accelerating learning and creating self-reinforcing development.

## **Diagnostic and predictive capacity**

This dynamic view enables diagnosis and prediction. A program stalled at 'information' may not need more data but enhanced capacity-building activities (*e.g.*, facilitation, and peer learning networks) or strengthened ETOLL. A failure to achieve empowerment may stem from inadequate mobilizing or coordinating activities, insufficient demonstration and mentoring, trust deficits, ethical misalignment, and/or a lack of transparent communication and inclusive decision-making. By quantifying both state achievement (*e.g.*, knowledge scores) and process effectiveness (*e.g.*, specific Extension activity metrics and ETOLL strength), Extension programs can identify specific barriers and leverage points (Meadows, 2015). Living labs provide active feedback where this system is observed, measured, and adapted.

## **Methods for Conceptual Model Application**

### **Case study selection and theoretical analysis**

To demonstrate its diagnostic logic and generate hypotheses, we conducted a theoretical retrospective analysis of five diverse Extension contexts. This exercise illustrates the model's potential explanatory utility and identifies specific predictions for future empirical testing. Case studies were selected to represent varying scales, geographies, and challenges: (1) per- and polyfluoroalkyl substances (PFAS) contamination response in Maine, USA; (2) digital Extension in Kenya; (3) 4-H youth civic engagement in USA; (4) European agricultural innovation living labs; and (5) urban agriculture health and safety education in Oklahoma, USA. For each case, we mapped outcomes to DETOLL, hypothesized bottlenecks, and examined alignment with framework prescriptions. This thought experiment validates the framework's conceptual coherence and diagnostic logic.

## **Linking Cooperative Extension activities to capacity dimensions**

A core utility of DETOLL is its ability to map standard Extension service categories to capacity-building processes. This cognitive mapping enables Extension practitioners to diagnose which capacity dimensions are underdeveloped and strategically deploy specific Extension activities to address identified gaps.

Education and outreach programming primarily drives the development of information→knowledge transformations, building cognitive capacity.

Technical assistance and advisory services enhance knowledge→wisdom progression, building adaptive capacity, while often strengthening trust.

Youth development (4-H) simultaneously integrates activities across multiple processes (data→information, information→knowledge, and knowledge→wisdom) and builds all capacity dimensions, particularly social (peer networks) and adaptive (experiential learning).

Applied research translation and demonstration accelerate knowledge→wisdom transformations via validations and evidence-based practices, while establishing living labs that strengthen all the capacity dimensions.

Community and socio-economic-ecological system development directly target institutional and social capacities through partnership development (*e.g.*, restructured or reoriented organization) and collective action facilitation (wisdom→empowerment), while ensuring equity considerations (ethics).

Administration and compliance provide the organizational infrastructure necessary to sustain all other Cooperative Extension activities.

## **Evaluation metrics**

Table 2 presents measurable indicators for data→empowerment transformations and ETOLL enablers. This integrated evaluation maintains accountability while providing strategic levers for Extension program improvement. Mixed-method approaches combining quantitative metrics with qualitative documentation are recommended (Creswell and Plano Clark, 2017). Metrics should be locally adapted and calibrated through participatory processes within living labs. Capacity-dimension mapping enables systematic diagnosis of which community capacities are underdeveloped and guides targeted intervention.

Table 2. Measurable indicators for DETOLL and associated capacity dimensions.

Transformation/enabler	CE activity indicators	Measurement approach	Capacity	CE practitioner application	Community application
Data→information	Time from data collection to tailored delivery; % receiving contextualized information	Process tracking, surveys, distribution logs	Cognitive	Identify workflow bottlenecks	Assess information accessibility and timeliness
Information→knowledge	Pre/post-assessment scores; frequency of applying principles locally	Validated assessments, case-based evaluations, attendance records	Cognitive	Evaluate teaching effectiveness	Measure capacity to adapt knowledge
Knowledge→wisdom	Quality of decision journals; observed adaptation of practices	Rubric-scored analysis, on-site documentation, interviews	Cognitive, adaptive	Assess contextual adaptation capacity	Reveal practical wisdom development
Wisdom→empowerment	Multi-season adoption rates; formation of cooperatives; policy advocacy	Longitudinal tracking, network analysis, policy records	Adaptive, social, institutional	Assess capacity to catalyze collective action	Track transition to community-wide empowerment
Empowerment→data	New data streams generated; citizen science participation; community-led documentation	Data source inventories, participation tracking, quality assessments	Cognitive, adaptive	Confirm feedback loop activation	Demonstrate community ownership of knowledge generation

Transformation/enabler	CE activity indicators	Measurement approach	Capacity	CE practitioner application	Community application
Ethics	Equity audits; stakeholder value alignment surveys; diversity in leadership	Demographic analysis, Likert-scale surveys, qualitative interviews	Institutional	Ensure equitable resource distribution	Verify fair benefit distribution and authentic voice
Trust	Longitudinal trust scores; peer-to-peer information sharing frequency; conflict resolution	Validated trust instruments, social network analysis, conflict tracking	Social	Monitor relationship quality and credibility	Assess confidence in Extension and peer networks
Organization	Resource adequacy; partnership functionality; facilitator-to-participant ratios	Resource audits, partnership assessments, staffing analysis	Institutional	Identify capacity gaps and partnership needs	Evaluate support adequacy for sustained action
Living lab	Stakeholder diversity; co-creation output frequency and quality; iteration cycles; scaling readiness	Demographic tracking, innovation documentation, iteration tracking	All	Assess validation environment effectiveness	Gauge meaningful participation in innovation

## Results

The following case study analyses illustrate DETOLL's diagnostic logic through theoretical application to diverse Extension contexts. These thought experiments retrospectively apply the framework to previously reported cases. These generate hypotheses about causal mechanisms, as formal validation requires prospective testing with the instruments from Table 2.

### **PFAS contamination response (Maine, USA)**

*Background and traditional approach:* PFAS contamination of agricultural land in Maine has created an urgent, complex challenge for Extension (Maine DACF, 2025). The response provided extensive data (e.g., soil tests) and information (e.g., risk advisories), but movement toward community-led action stalled despite available knowledge (Heard, 2025).

*DETOLL diagnosis:* Primary bottlenecks were inadequate knowledge (e.g., knowledge of PFAS risks)→wisdom (e.g., ability to implement farm-specific responses) and wisdom→empowerment (e.g., absent collective action infrastructure) achievements, with some deficits in all the ETOLL enablers (e.g., matrix-testing frequency and diversity and equitable compensation and transition support). This pattern indicated high cognitive capacity but low adaptive, social, and institutional capacities.

*DETOLL prediction and alignment:* The framework posits that isolated information campaigns would fail, and that integrated interventions addressing all ETOLL deficits would be necessary. Documented successful interventions (e.g., third-party testing: ↑trust; transition partnerships: organization; and state compensation funds: ↑ethics) align with this prescription, providing a mechanistic rationale for their combined success (Maine DACF, 2025).

## **Digital extension in Kenya**

*Background and traditional approach:* Digital platforms (e.g., DigiFarm) excelled at data→information transformation (SMS advisories) but showed limited long-term retention.

*DETOLL diagnosis:* Bottlenecks occurred at information→knowledge and knowledge→wisdom due to the absence of support for contextual adaptation in digital-only models, compounded by weak trust and organization (Wyche and Steinfield, 2016; Tsan et al., 2019).

*DETOLL prediction and alignment:* The framework predicts high initial data→information success but poor sustained empowerment without ETOLL investment. Platforms that achieved higher retention integrated local agent networks (enabling knowledge→wisdom and ↑trust) and service-bundling partnerships (↑organization), validating the need to complete the full data→empowerment cycle with ETOLL support (Tsan et al., 2019).

## **4-H youth civic engagement (USA)**

*Background and traditional approach:* Programs effectively build skills (advancing data→information and information→knowledge) but vary in achieving sustained community leadership (Bozeman, 2020).

*DETOLL diagnosis:* The gap between skill-building and leadership reflects weak knowledge→wisdom and blocked wisdom→empowerment transformations, stemming from deficits in youth agency, youth-adult partnerships, and institutional support (Arnold and Gagnon, 2020).

*DETOLL prediction and alignment:* The framework predicts skill-building alone yields low sustained engagement, whereas integrated ETOLL strengthening is required. Documented superior outcomes from programs with youth-adult partnership protocols,

dedicated mentorship, and institutional support confirm this, framing these features as essential investments in specific transformation processes (Arnold and Gagnon, 2020).

### **European agricultural innovation living labs**

*Background:* The European Innovation Partnership (EIP-AGRI) established operational groups as living labs for co-innovation (Pineiro et al., 2021).

*DETOLL diagnosis and prediction:* These living labs inherently operationalize DETOLL principles: co-design manages information→knowledge, on-farm trials manage knowledge→wisdom, and formal agreements build trust and organization. The framework therefore predicts higher efficacy than linear transfer models.

*Validation:* Meta-analyses confirm 30-50% higher adoption rates (Pineiro et al., 2021). Empirical data shows information→knowledge success correlates with co-design intensity ( $r = 0.68$ ) and wisdom→empowerment success with trust levels ( $r = 0.71$ ) (Harrhill et al., 2022), validating the framework's internal logic.

### **Urban agriculture health and safety education (Oklahoma, USA)**

*Background and traditional approach:* A Borich needs assessment (Campbell et al., 2025) identified priority gaps among urban producers (e.g., pesticide safety). Traditional approaches provided generic agricultural safety information but failed to generate urban-contextualized knowledge or wisdom.

*DETOLL diagnosis:* The high importance/low knowledge scores indicate a primary blockage in the information→knowledge transformation due to a lack of validating activities tailored to urban contexts. A secondary knowledge→wisdom bottleneck existed due to absent demonstrating activities (e.g., mentorship on urban plots). Underlying these were critical ETOLL deficits, such as historical rural focus, lack of urban producer networks, and concerns regarding equitable resource allocation. This reflected a severe underdevelopment of adaptive capacity and institutional capacity.

*DETOLL prediction and alignment:* The framework predicts that generic information dissemination would fail. Success would require integrated interventions to: (1) enable information→knowledge via urban-specific knowledge synthesis; (2) enable knowledge→wisdom via demonstration in living labs (e.g., community gardens); and (3) strengthen ETOLL via urban producer networks (↑trust and organization) and dedicated specialist support (↑organization and ethics). This prescriptive design directly aligns with emerging best practices for urban Cooperative Extension.

Table 3 synthesizes the diagnostic and predictive insights from theoretically applying DETOLL across the five cases, demonstrating its utility in explaining diverse Cooperative Extension program outcomes. DETOLL provides a consistent, mechanistically coherent lens for diagnosing failure mechanisms and predicting success factors across vastly different Cooperative Extension contexts, even when applied retrospectively as a conceptual tool.

Table 3. Cross-case theoretical analysis using DETOLL

Case study	Hypothesized data→empowerment bottleneck	Capacity gap	ETOLL deficits	DETOLL-aligned intervention	Explanatory value
Maine PFAS	Blocked knowledge→wisdom and wisdom→empowerment	Adaptive, social, institutional	Ethics, trust, and organization	Third-party testing, partnerships, compensation	Explains why information failed; why integrated ethics, trust, and organization interventions were necessary.
Kenya Digital	Incomplete information→knowledge, knowledge→wisdom, and wisdom→empowerment	Cognitive, adaptive	Trust and organization	Local agent networks, multi-sector partnerships	Explains retention gap: ETOLL enablers essential for completing the data→empowerment cycle.

Case study	Hypothesized data→empowerment bottleneck	Capacity gap	ETOLL deficits	DETOLL-aligned intervention	Explanatory value
4-H Youth	Incomplete knowledge→wisdom and blocked wisdom→empowerment	Adaptive, social, institutional	Ethics, trust, and organization	Youth-adult protocols, mentorship, support	Explains efficacy difference: ETOLL investments enable knowledge→wisdom and wisdom→empowerment processes.
EU LLs	Optimized information→knowledge; variable wisdom→empowerment	Adaptive, social, institutional	Trust and organization	Formal co-innovation agreements	Validates the framework: correlations confirm ETOLL as leverage points (co-design intensity $r = 0.68$ ; trust $r = 0.71$ ).
Oklahoma Urban Ag	Blocked information→knowledge and knowledge→wisdom	Cognitive, adaptive	Ethics, trust, and organization	Urban-specific knowledge synthesis, producer networks, dedicated support	Transforms need assessment from a list to a system diagnosis; predicts why generic info fails and urban-specific, ETOLL-integrated programming is essential.

## Discussion

### Model value proposition

DETOLL is a conceptual model for program design and hypothesis generation. The case study analyses in Results serve an illustrative function and demonstrate how the model would diagnose bottlenecks if its constructs were measured. The model's value depends on prospective empirical testing using the measurement approaches outlined in Table 2. DETOLL advances beyond the logic model in four areas:

- (1) Mechanistic diagnosis pinpoints which transformation is constrained and which ETOLL enabler is deficient, diagnosing root causes rather than documenting symptoms.
- (2) Predictive capacity forecasts impact of different intervention strategies by modeling processes and ETOLL enablers as transformation rates.
- (3) Capacity-building focus operationalizes community and socio-economic-ecological system development as strengthening the four measurable capacity dimensions, providing a metric for impact beyond knowledge gain. The framework models their combined effect as a multiplicative product, explaining why isolated successes in one dimension often fail to generate empowerment.
- (4) Dynamic management and learning embed adaptive management through living labs and the empowerment→data feedback loop, positioning Extension as a learning organization that improves iteratively (Franz and Townson, 2008; Kennedy et al., 2025).

### **Interdisciplinary contributions**

DETOLL advances Extension science by providing the first integrated, operationalized approach that explicitly models the cognitive-to-action pathway as a reinforcing feedback system, quantifies governance mechanisms as active enablers, and embeds structured validation environments. This synthesis addresses a critical methodological void identified in recent Extension evaluations (Kennedy et al., 2025; Nin-Pratt and Stads, 2023): the absence of frameworks that can both explain why programs succeed or fail and predict which interventions will optimize outcomes. By bridging systems dynamics, participatory innovation, and social capital theories within an Extension context, DETOLL provides practitioners with an evidence-based tool for transitioning from descriptive outcome documentation to predictive, mechanism-based program design.

### **Implications for Cooperative Extension practices**

The framework provides direct guidance for redesigning core Extension functions:

Program design: selects activities based on the specific data→empowerment progression (*e.g.*, workshops for information→knowledge and mentorship for knowledge→wisdom).

Evaluation: tracks both state levels (*e.g.*, knowledge scores and trust indices) and process effectiveness (*e.g.*, quality of demonstration activities).

Resource allocation: prioritizes strengthening the ETOLL enablers identified as critical bottlenecks (multiplicative effects across the system).

Professional development: trains staff in systems thinking and facilitation skills to manage social and institutional processes that enable technical transitions.

Living lab implementation: uses small-scale pilots for iterative testing of interventions and generating empirical feedback on transformation rates and ETOLL effectiveness before scaling up.

### **Systemic failure diagnosis and mechanism explanation**

DETOLL exposes systemic barriers that traditional Extension models miss by revealing the specific mechanisms through which apparently adequate inputs fail to produce expected outcomes. For example, the failure of the U.S. National Animal Identification System, despite strong data and information components, was a trust deficit between ranchers and government agencies (Greene, 2010)—a knowledge→wisdom bottleneck. Similarly, barriers to agricultural innovation impact in Burkina Faso stemmed not from inadequate technical knowledge but from weak institutional organization including inadequate Extension staffing, limited inter-agency coordination, and insufficient farmer organization support (Hartmann et al., 2020).

## Limitations and Future Research

DETOLL has four principal limitations. First, it lacks empirical validation since the case study analyses generate hypotheses. For example, diagnostic claims (*e.g.*, PFAS failures stem from blocked knowledge→wisdom and wisdom→empowerment transformations) remain untested hypotheses until confirmed with the instruments from Table 2. Second, the operational definitions (Table 1) and measurement indicators (Table 2) are not psychometrically validated. Instruments for the state variables (*e.g.*, wisdom) do not exist in the Extension evaluation literature and require *de novo* development. Third, it does not specify transformation time scales. Rates of change between data→empowerment states likely vary by context (*e.g.*, information→knowledge may take months in agriculture but years in public health). Finally, its generalizability across diverse cultural, socio-economic, and institutional contexts remains undemonstrated since the five case studies are geographically concentrated in Western Extension contexts.

Key research priorities include: (1) developing validated instruments to measure data→empowerment states and ETOLL strength (Kaplan and Norton, 1996; Mayer and Davis, 1999; Colquitt, 2001); (2) conducting longitudinal, comparative case studies of DETOLL-informed vs. traditional programs (Schuurman et al., 2016); (3) creating practical toolkits and dashboards for practitioner use (Kennedy et al., 2025; Nin-Pratt and Stads, 2023); and (4) testing the framework's applicability in non-agricultural Extension domains (*e.g.*, health and community development).

## Conclusions

DETOLL presents a coherent, theory-grounded strategy that may transform Extension from a knowledge-delivery service into a catalyst for measurable community empowerment. It models the data-to-empowerment pathway as a dynamic system moderated by ethical, social, and institutional enablers. This theoretical application across five case studies demonstrates that program failures often stem from underinvestment in the later-stage transformations (knowledge→wisdom and

wisdom→empowerment) and the ETOLL capacities. DETOLL provides the diagnostic logic to explain these failures and the predictive insights to design interventions that build the cognitive, social, institutional, and adaptive community capacities essential for socio-economic-ecological system stability. We recommend its rigorous empirical testing and refinement as a pathway to evidence-based, impact-driven Extension programming. By providing a mechanism-based blueprint for impact, DETOLL equips Extension to credibly demonstrate its vital role in building resilient communities and socio-economic-ecological systems.

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