Modelling Collaborative Learning Among Teachers Using Systems Thinking

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Abstract

This paper describes the development of a systems-based reference model to support teachers in learning about collaborative learning among teachers. By representing collaborative dynamics into a formal model, the project offers a tangible means to support sustained, collective professional growth. The research used a practice-based, design-oriented methodology. Insights from the activities informed the development of the reference model and a learning guide which help teachers navigate the modelling process. Despite time constraints limiting deep individual use, participants were able to co-construct and apply the model to their practice in meaningful ways. Findings show the potential of systems thinking to enhance collaborative learning. Future work will refine the model and expand its integration into teacher development pathways.

1 Introduction

Collaborative learning among teachers refers to a structured, cooperative process in which professionals jointly explore complex educational issues and enhance their practice [17]. It emphasizes mutual engagement, shared responsibility, and continuous reflection. For such learning processes to be sustainable, several conditions must be met: psychological safety within teams [9], clear boundaries and expectations [12], autonomy and ownership of the learning process [5, 27, 37], and dedicated time for deep reflection and dialogue ("slow time") [38]. When collaborative learning is structurally embedded in school practices, it can evolve into organizational learning—a broader, institutionalized approach to building capacity [2, 29]. This transformation requires intentional knowledge sharing, supportive leadership, and alignment across people, processes, and technologies [14, 34].

Although the term collaborative learning is widely used, its meaning often remains vague and underdefined, and its dynamics complex [11, 18, 40]. This study aims to offer conceptual clarity in a practical format that helps teachers to understand and engage with collaborative learning as a dynamic, systemic process. This led to the following research questions: (i) how can the know-how related to collaborative learning be made more concrete? and (ii) in what ways can this practical application of know-how be visualized to encourage teachers to learn about collaborative learning?

To address the questions, a systems thinking approach was adopted. This theoretical perspective emphasizes patterns, relationships, and dynamics within collaborative learning, aiming to unravel its inherent complexity [15]. One proposed strategy involved the development of a Causal Loop Diagram (CLD), to conceptualize collaborative learning through dialogue. Based on the CLD, a qualitative reference model was created, using DynaLearn (https://dynalearn.eu), as a visual representation of the collaborative learning process. This model was subsequently simplified to enable teachers to construct and simulate their own conceptual model, thereby supporting experiential learning.

This paper presents the development and implementation of this model. It outlines the structure of the model and describes the steps taken to translate it into a practical version tailored to teachers' daily practice.

2 Methodology

The aim of this study was to explore how systems thinking—operationalized through modelling techniques—can help teachers understand and engage with collaborative learning as a dynamic social system. The methodology consisted of three intertwined components: (i) exploratory groundwork through data collection, (ii) construction of a CLD as a conceptual foundation, and (iii) development and validation of a formal reference model using DynaLearn.

2.1 Research Design and Approach

This study employed a practice-based, design-oriented research methodology [8], grounded in iterative refinement and stakeholder engagement. Key stages include:

1. Semi-structured interviews and group reflection sessions with over 30 teachers from three teaching teams in the same secondary school.
2. Thematic analysis of data and literature on collaborative learning.
3. Construction of systems models.
4. Expert validation and user feedback cycles.

2.2 Construction of the CLD

To capture the dynamics of collaborative learning, the study first developed a CLD, a technique from system dynamics that visualizes patterns and feedback loops within complex systems. The CLD was based on:

- Teacher responses to prompts about team, organizational, and supervisory support for collaboration.
- Recollections of success and failure in collaborative situations.
- A review of relevant scholarly literature.

The diagram was built using a structured protocol [cf. 42] which consisted of five main steps, embedded within a broader process that includes a preparatory (pre) and a follow-up (post) phase: Pre: delineate the issue and diagnose from multiple viewpoints, (a) use your gut feeling to pick the top 10 factors out of the full range of data; sense a storyline, draw loops and fill in the gaps, (b) check arrows for cause and effect: more of this = more/less of that, (c) walk through the diagram; redraw it as a recognizable set of circles, (d) deduce and discuss points of leverage & monitoring, and post: testing and using the diagram to affect change.

Thematic coding of this data identified recurrent patterns and conditions, which were translated into loops reflecting reinforcing and balancing dynamics central to collaborative learning, visualized in Kumu (https://kumu.io).

2.3 Transformation into a Causal Model

Building on the CLD, a causal model was constructed using the DynaLearn software. This model was presented as a reference model, in this context, an expert-validated, abstract framework capturing the essential quantities and mechanisms of a process [4]. Steps included:

1. Categorizing and refining key factors from qualitative data and theoretical sources (Table 1).
2. Translating these into system components—categories, properties, and causal relationships (Table 2). This transformation from a list of key factors to a systemic model was guided by principles: (a) identifying overlap and redundancy [33], (b) focusing on key components [28], (c) assessing controllability [33].
3. Integration of cause-effect pathways from literature to substantiate the model dynamics (Table 3).
4. Iterative model development and simplification based on expert validation and user's feedback.

2.4 Modelling in DynaLearn

The DynaLearn environment was used to operationalize the reference model. DynaLearn supports simulation of qualitative system dynamics [22], with features such as:

- Entities and quantities to represent system components and changing states.
- Causal dependencies and correspondence rules to simulate interactions and feedback loops.
- Exogenous factors to account for fixed values during the entire simulation.

2.5 Teacher-friendly Essentials

Multiple rounds of modelling led to the development of both a formal reference model and a simplified, teacher-friendly version that allowed teacher's individual construction of a conceptual model. This process was supported by a tailored learning guide for teachers. Strategies to simplify the reference model included (as in 2.3): (a) Identifying overlap and redundancy [33], (b) Focusing on key components [28], and (c) Assessing controllability [33].

3 From Exploration to CLD

The study began with an exploratory phase aimed at conceptualizing collaborative learning as a social system within teacher teams. Drawing on data from interviews, group reflections, and literature, the research identified a spectrum of factors influencing collaborative learning—spanning organizational, interpersonal, and individual dimensions. To structure and visualize these insights, a CLD was developed [41]. The resulting representation served as a diagnostic tool and a foundation for further modelling. It depicts patterns to explore, in an exculpatory way, where obstacles lie that have prevented collaborative and organizational learning from coming to fruition [31].

3.1 Data Collection and Thematic Analysis

Data for the CLD were gathered through brainstorm sessions and group reflections, with 30 teachers, and literature review. During the brainstorm teachers were asked:

- What do you need from the team to learn more with and from each other?
- What do you need from the organization to learn more with and from each other?
- What do you need from your supervisor to learn more with and from each other?
- What do you bring yourself to learn more with and from each other?

During group reflections, the following questions were asked:

- What have been the milestones and what contributed most to learning with and from each other?

During interviews the teacher was invited to recall an example in which there were primarily success factors and one in which there were primarily impeding factors for collaborative and organizational learning.

The collected data were thematically analyzed, with causal relationships and interdependencies identified following Vermaak's protocol [42]. The emerging insights were translated into dynamic feedback loops and visualized in a CLD (Fig.1) using the Kumu platform (https://kumu.io).

Fig. 1. Diagram of patterns of collaborative and organizational learning among teachers.

The CLD (Fig. 1) reveals that *personal involvement and motivation* drive *professional development and growth*, which in turn enhances *trust and support*, leading to increased *appreciation*. These elements also foster *professional safety*, enabling stronger *collaboration and communication*, which contributes to a *collective willingness* to engage in collaborative learning. Ultimately, this results in greater *collective contribution* and deeper *learning experience*. These outcomes feed back into the system by creating *professional space* and promoting *flexibility and innovation*, which again enhance *appreciation*, forming reinforcing feedback loops central to sustainable collaborative and organizational learning.

4 Construction of the Reference Model

To support teachers in building and simulating a qualitative model of collaborative learning as a dynamic system, a reference model was developed using DynaLearn. This model serves as a normative model to guide understanding of the systemic nature of collaborative learning.

A reference model, in this context, refers to an abstract, domain-specific ontology consisting of a coherent set of well-defined concepts [4]. Developed by experts, such models foster shared understanding and effective communication, especially in complex domains. They also support systemic analysis, promote standardization, and enhance conceptual clarity across stakeholders.

4.1 Data Collection and Thematic Analysis

The construction of a reference model necessitated a different level of formalization. In the CLD, dynamic patterns are visualized by abstracting specific factors from a complex reality.

Yet, beneath these patterns lies a deeper layer of systemic interdependencies. The reference model seeks to capture the underlying structure, with a particular emphasis on collaborative learning. To achieve this, the data from teacher sessions, along with relevant literature, were revisited and subjected to further analysis. Data were thematically categorized, and key factors and conditions associated with collaborative learning were identified (Table 1).

Table 1. Key factors - Key factors mentioned by teachers are presented as categories, added by sources from scholarly literature numbered for literature references (see References).

Educational issue	**Team development**	**Team attitude**
1 Team organization Competence [12, 40]; Expertise [3, 36]; Responsibility [1, 11]; Role and task distribution [3, 36]	1 Professional development Consolidation [2, 7]; Evaluation [11, 39]; Flexibility & Innovation Knowledge sharing [2, 7]; Professional development & growth	1 Communication Communication; Listening [3, 36, 16]
2 Approach Clear structure; Method [1, 11]; Objective [21, 36]	2 Professional safety Appreciation; Empowerment [21, 27]; Honesty; Professional safety [21, 27]; Respect; Trust & support	2 Collaboration Collaboration; Keeping agreements [12, 40]; Open attitude [16]
3 Conditions Funding [9, 25]; Physical space/location [9, 25]; Team composition [12, 40]; Time [9, 25]; Urgency [24, 44]	3 Professional space Agency [26, 27]; Autonomy [5, 37]; Professional space; Professionality [37]	3 Develop together Collective contribution & learning experience; Collective willingness; Giving feedback [11, 39]; Personal involvement & motivation; Receiving feedback [11, 39]; Reflection [11, 39]; Willingness to grow [24, 44]

4.2 Reasoning Framework

The development of the reference model in DynaLearn followed a structured, analytical process. Initially, a broad inventory of key factors was compiled (Table 1), drawing both from data—teacher interviews and sessions —and the existing literature. These key factors, while insightful, were still relatively unstructured and overlapping. Therefore, a second step was required: organizing these factors into a coherent system with measurable quantities that reflects how collaborative learning operates in practice. This transformation from a list of factors to a systemic model (Table 2) was guided by several underlying principles:

- Identifying overlap and redundancy. Look for elements that serve similar roles or have overlapping effects, and consolidate them to reduce complexity [33].
- Focusing on key components. Prioritize elements that are critical to the system's behavior and outcomes, and consider omitting less influential components [28].

- Assessing controllability. Determine which components can be influenced or controlled in practice, and focus the model on those [33].

Table 1 lists the various elements related to collaborative learning, derived from the data. These elements were subsequently translated into a set of properties, with an effort to reduce conceptual overlap. For instance, elements such as *role and task distribution, method, consolidation, structure, physical space/location, funding,* and *opportunity* were grouped under the overarching property *structure*. It is not necessary for every original element to be included individually to represent the essential dynamics of the collaborative learning system.

Once the changing properties were identified, they were further organized into categories that define the core concepts of the model. For example, *psychological ownership, autonomy, accountability*, and *evaluation* were grouped together under the category *behavioral mechanisms* (Table 2). This process allowed for a theoretically grounded and empirically informed system model that captures the dynamic, multilevel and interactive nature of collaborative learning among teachers.

Table 2. From key factors to properties and categories.

Elements	Properties	Categories
Expertise, Competence	Functional fit	Educational issue
Willingness to grow	Relatedness	
Role and task distribution, Method, Consolidation, Structure, Physical space/location, Funding, Opportunity[1]	Structure	Contextual parameters
Objective, Urgency	Organizational fit	
Responsibility, Agency, Empowerment	Psychological ownership	Behavioral mechanisms
Autonomy	Autonomy	
Professionality	Accountability	
Reflection	Evaluation	
Motivation	Commitment	Team dynamics
Appreciation, Support, Listening, Respect, Honesty, Trust, Giving feedback, Receiving feedback	Psychological safety	
Diversity[2]	Diversity	
Individual learning outcome[3]	Individual learning outcome	Outcome
Collective learning outcome[4]	Collective learning outcome	
Flexibility, Innovation	Quality development	

[1] Opportunity was added as a result of the literature review.
[2] Diversity was added as a result of the ongoing literature review.
[3] & [4] Individual and collective learning outcome were added after expert feedback indicating the end of the collaborative learning.

From now on, categories are referred to as entities and properties as quantities, both structured within a process-oriented model starting from an educational challenge and ending with tangible outcomes (Fig. 2). Inspired by reference models in other domains (e.g., climate systems, water governance, https://dynalearn.eu), a systems thinking approach was used to capture these elements in a framework.

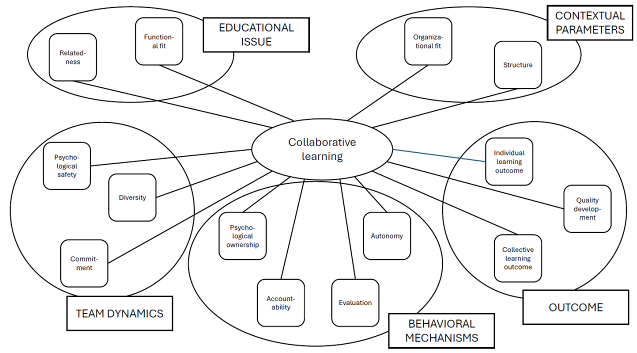

Fig. 2. Collaborative learning as a process-oriented model.

4.3 Integration of Formal Pathways

The simulation logic of the reference model is grounded in rigorously derived causal relationships among key system quantities, based on literature. These causal pathways form the foundation for simulating system behavior over time in DynaLearn [6]. The model represents time as a sequence of qualitatively distinct system states, visualized as a state graph [13]. Each state captures a specific behavioral mode of the system, characterized by a unique set of constraints on the values of relevant quantities. This structure enables the model to simulate how the system evolves and transitions between different behavioral regimes.

Table 3. Causal dependencies based on literature - See References for the sources of the numbers.

Related quantities
Relatedness → Commitment [18,19]
Functional fit → Individual and Collective learning outcome, Quality development, Commitment [11, 21]
Individual learning outcome → Collective learning outcome [32, 40]
Collective learning outcome → Quality development, Individual learning outcome [18, 20]
Structure → Commitment, Quality development [5, 36]
Organizational fit → Quality development [7, 23]
Diversity → Collective learning outcome, Quality development [10, 30]
Evaluation → Individual learning outcome, Collective learning outcome, Quality development [11, 26, 35]
Psychological ownership → Commitment [12, 27]
Accountability → Psychological safety [17, 43]
Autonomy → Individual learning outcome, Collective learning outcome [5, 7]
Psychological safety → Commitment [11]

5 The Reference Model

By combining the entities, quantities, and causal dependencies in a model using DynaLearn, the representation of collaborative learning is shown in Fig. 3. Table 4 explains the symbols.

Table 4. Legend.

Entity	Quantity
Direction of change {-,Ø,+}	Decreasing quantity
Cause and effect relation	Simulation with one state
Quantity space - range of values	Correspondence
Exogenous factor Type: constant	

5.1 Enhancing the Reference Model

Several enhancements were made to increase the model's usability and its alignment with both theory and practice:

- Integration of *evaluation* as a core quantity. *Evaluation* was added as a distinct and central quantity. This decision reflects its strong theoretical grounding [11, 39] and its relevance in practice, were teachers frequently cited *evaluation* as essential for professional growth.
- Specification of quantity spaces. To simulate variable behaviors more accurately, value ranges were introduced for four key quantities: *evaluation, individual learning outcomes, collective learning outcomes,* and *quality development.* These intervals allow the model to reflect gradual change, thresholds, and potential plateaus.
- Causal link between *evaluation* and *quality development.* Literature supports a strong association between *evaluation* and *quality development* [11], which was formalized as a correspondence link in the model. This means that higher levels of *evaluation* correspond to higher levels of *quality development*.

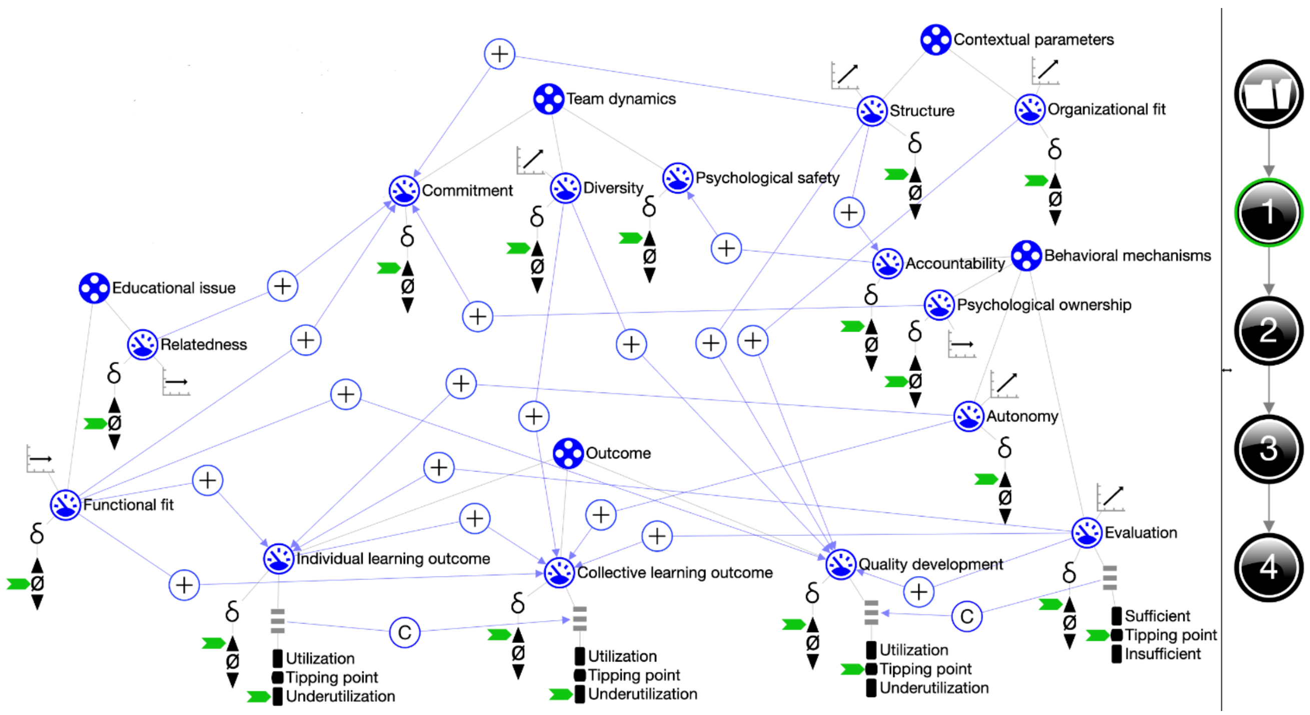

Fig. 3. The reference model.

The model consists of 5 entities (*educational issue, contextual parameters, team dynamics, behavioral mechanisms and outcome*). Each has quantities,16 in total. The left side displays the conceptual model under conditions of steady *functional fit*, influenced by an exogenous factor. In this situation, direction of change for *relatedness* is set to Ø, while *organizational fit* and *structure* are set to +. *Diversity* is +, whereas *commitment* is –. *Psychological ownership* is –, while *accountability*, *evaluation*, and *autonomy* are +. The current value of *evaluation* is positioned at the *tipping point*. Notably, *evaluation* corresponds with *quality development*. Both *collective learning outcome and individual learning outcome* are set to *underutilization*.

The right side of the figure presents the simulation results. In state 1, under these specific conditions, *quality development* increases, with its value remaining at the *tipping point*. *Individual learning outcome* also increases, even though its value remains at *underutilization*. The same pattern applies to the *collective learning outcome*. *Commitment* decreases, whereas *psychological safety* rises.

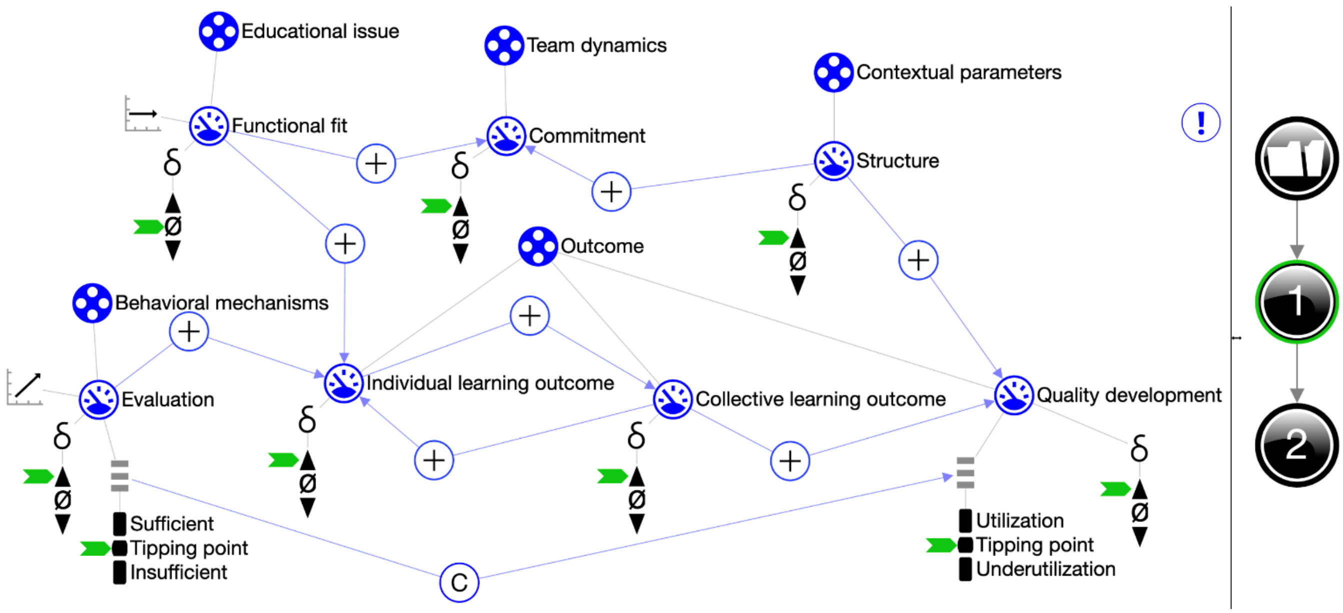

Fig. 4. The teacher's conceptual model on collaborative learning.
Although this model is simplified compared to the reference model in Fig. 3, it has the same settings and can be read in the same way.

- Stabilization through exogenous factors. To prevent erratic behavior during simulation, some quantities—such as *evaluation* and *functional fit*—were modelled as exogenous factors with fixed values. For example, *evaluation* is designed to consistently rise over time, reflecting teachers' growing awareness of its importance, despite practical challenges.

5.2 Simplification of the Reference Model

To make the reference model accessible and usable for teachers, it was systematically simplified. The simplified model was designed to be both accessible and actionable wihtin the DynaLearn environment, enabling teachers to simulate and explore systems dynamics inependently. This model underwent multiple iterations based on user feedback and expert validation. The simplification process followed the same methodological approach as described in Section 4.2: identifying overlap and redundancy, focusing on key components, and addressing controllability.

- Identifying overlap and redundancy. An audit confirmed that the selected components from Table 2 were both essential and non-redundant. No elements were removed for overlap.
- Focus on key components. Key components were translated into a simplified model. A substantial simplification involved the reduction of quantities. Table 3 was used to identify quantities with limited causal dependencies. As a result, *relatedness, diversity, organizational fit, psychological safety, psychological ownership*, and *accountability* were removed from the model.
  Interestingly, *commitment* was retained despite having no direct causal influence in the model. Its inclusion acknowledges teachers' common perception that *commitment* drives outcomes, offering an entry point for reflective dialogue.
- Controllability. Finally, the model emphasized quantities that teachers can directly influence, such as *structure, evaluation,* and *behavioral mechanisms*. Quantity spaces were preserved for *evaluation* and *quality development* to capture meaningful variance. To reduce complexity, quantity spaces for *individual* and *collective learning outcomes* were omitted.

This resulted in the teacher's version of the conceptual model on collaborative learning as presented in Fig. 4.

5.3 Learning Guide Steps and Insights

A tailored learning guide was developed to help teachers navigate the modelling process. Instead of presenting the entire system at once, it introduces key components in a phased, hands-on manner.
Step 1: Model construction – Teachers define key entities and causal relations. Initial simulations show how increases in *evaluation* drive improved *individual learning outcome.*
Step 2: Introducing ambiguity – Teachers explore how ambiguous system behavior arises when multiple quantities interact (e.g., rising *evaluation* paired with declining *functional fit*), reflecting real-world complexity.
Step 3: Expanding the model – *Collective learning outcome* and *quality development* are added, revealing reinforcing

feedback loops between individual and team-level learning.
Step 4: Refinement through tuning of quantities – Teachers observe how *evaluation* may plateau or underperform, prompting refinement of quantities and leverage points to clarify value ranges and reduce ambiguity.
Step 5: Exogenous factors – External influences are introduced as fixed drivers that sustain systemic change. *Functional fit* remains constant while *evaluation* increases, illustrating the tension between systemic needs and practical constraints.
Step 6: Co-occurrence patterns – Teachers simulate correspondence, showing how the alignment of *evaluation* and *quality development* influences overall system improvement.
Step 7: Reframing commitment – Teachers reflect on *commitment* not as a cause but as an outcome shaped by system *structure* and *functional fit*, encouraging more systemic thinking.

6 Teacher Involvement and Reflection

The step-by-step modelling process deepened understanding of teacher team dynamics and encouraged critical reflection. Piloted with users, the approach yielded feedback that shaped two versions of the model and learning guide: a regular and a light version (excluding quantity spaces, exogenous factors, and correspondence).

Although initially intended for independent use, time constraints made a co-constructive approach with the teachers more feasible. During sessions, teachers recognized elements of their own practice in the model, which fostered reflective dialogue, a shared language around collaborative learning, and connection of theory to professional experience—contributing to collective sense-making, a key aim of the model and broader development effort.

This iterative process also highlighted the importance of adaptability and contextual sensitivity in facilitating meaningful engagement with the model.

7 Conclusion

This study set out to explore how systems thinking—operationalized through the construction of a reference model—can support teachers in understanding and engaging with collaborative learning. Building a qualitative system model enabled a shift from viewing collaborative learning as a fragmented set of conditions to understanding it as a coherent, dynamic process.

Features such as real-time feedback, scenario simulations, instructional videos, and written explanations of components, quantities, and causal relations—provided through a learning guide—helped teachers navigate the abstract nature of systems modelling. This support was essential, given that the modelling process required significant cognitive effort and time investment.

However, challenges remain. The abstract nature of qualitative modelling, combined with existing workload pressures, limited the depth of engagement for some teachers. The original vision—where teachers would independently construct and refine their own models—was modified into a facilitated, collaborative process.

Despite this, once the co-constructed model took shape, it served as a catalyst for reflective dialogue and collaborative learning. Teachers began to link real-world experiences with systemic structures, leading to a richer and more grounded understanding of collaborative learning. This emergent, shared vocabulary around collaboration was one of the most meaningful outcomes, directly supporting the overarching goals of this project and the reference model initiative.

Building on these findings, the reference model contributes a model-building method in a non-exact domain, enriching the field of qualitative reasoning.

8 Limitations and Future Work

This study has several limitations. First, the sample was restricted to one secondary school context, which may limit the generalizability of the findings. Second, due to time constraints and the novelty of the modelling approach, teachers did not construct the model independently as originally intended. This may have reduced the depth of their individual learning experience. However, the shift toward a co-constructive process may have enriched the approach by grounding the model more directly in teachers' lived experiences and daily practice. Moreover, the current version of the model omits potentially important quantities, such as motivation—identified by participants as both an individual and collective driver of collaborative learning—and the use of reflection over evaluation, which may offer deeper insights into both individual and group learning processes. Future iterations should explore how these elements can be integrated and operationalized as measurable system components.

Further development and testing are planned, including improved alignment with ongoing professional learning trajectories. Research could focus on empirically evaluating the model's impact, with particular attention to collaboration with the target group. Applying and testing the model in varied educational contexts will be essential to strengthen claims of effectiveness and relevance. A comparative analysis with existing models of collaborative learning could also enhance the academic positioning and theoretical grounding of the current approach.

The approach presented in this paper can serve as inspiration for similar initiatives aiming to support professional learning in complex, social domains. Ultimately, the model aspires to become a practical tool that not only facilitates professional reflection but also fosters collaborative learning cultures within schools.

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