frontiers in Education

TYPE Original Research
PUBLISHED 19 February 2026
DOI 10.3389/feduc.2026.1723824



OPEN ACCESS

EDITED BY
Mary Koutselini,
University of Cyprus, Cyprus

REVIEWED BY
Roberto Capone,
University of Bari Aldo Moro, Italy
Semi Sukarni,
Universitas Muhammadiyah Purworejo,
Indonesia

*CORRESPONDENCE
Jöran Petersson
✉ joran.petersson@mau.se

RECEIVED 13 October 2025
REVISED 27 January 2026
ACCEPTED 30 January 2026
PUBLISHED 19 February 2026

CITATION
Basister MP, Petersson J and Baconguis RDT (2026) Deconstructing teachers' mental models of collaboration through Lesson Study between mathematics and special education teachers.
*Front. Educ.* 11:1723824.
doi: 10.3389/feduc.2026.1723824



# Deconstructing teachers' mental models of collaboration through Lesson Study between mathematics and special education teachers

Michel P. Basister[1], Jöran Petersson[1,2]* and Rowena D. T. Baconguis[1]

[1]College of Public Affairs and Development, Institute for Governance and Rural Development, University of the Philippines Los Baños, Laguna, Philippines, [2]Department of Natural Science, Mathematics and Society, Faculty of Education and Society, Malmö University, Malmö, Sweden

Achieving inclusive mathematics education remains a distinctive challenge due to the discipline's hierarchical structure, high degree of abstraction, and dense symbolism. These disciplinary features create unique cognitive barriers for students with special educational needs, requiring a precise intersection of content expertise and pedagogical scaffolding. While collaboration between mathematics and special education (SPED) teachers is vital to dismantling these barriers, the success of such teams is mediated by the teachers' mental models—the internal assumptions that dictate their collaborative engagement. Utilizing a multi-case study design, this study examined teacher mental models through cross-disciplinary Lesson Study (LS) focused specifically on making abstract mathematical concepts accessible. Based on data collected before, during, and after four LS cycles, findings reveal that participants' initial mental models of collaboration were limited to rudimentary idea-sharing. However, the LS experience facilitated a shift toward reciprocal learning, where participating teachers engaged in a mutual exchange of disciplinary expertise to co-create lesson resources and strategies. This shift is framed as a theoretical insight into cognitive syncretism: the restructuring of compartmentalized professional identities into a shared, integrated schema. Specifically, SPED teachers acquired the technical mathematical depth necessary to navigate cumulative curriculum demands, while mathematics teachers adopted differentiated strategies to decode complex mathematical symbols for diverse learners. Ultimately, this research positions mental models as primary mediators of educational reform, suggesting that sustainable inclusion in mathematics requires a fundamental cognitive reorganization of how teachers perceive the intersection of mathematical rigor and instructional accessibility.

KEYWORDS
**inclusive mathematics education, lesson study, mental models, models of collaboration, teachers' collaboration**

# 1 Introduction

While mathematics is a critical doorway to employment and academic opportunity, marginalized groups (including people of color, women, and children with special educational needs) continue to face long histories of challenges and deprivation in mathematics education (Joseph et al., 2017; Larnell, 2016; Martin et al., 2017; Shah, 2017; Zavala, 2014). The absence of mathematical knowledge contributes directly to societal injustices and educational hierarchies (Gutiérrez, 2013; Martin, 2019). In response, various mathematics educational reforms have been implemented to address access, inclusion, and other education-related issues, thereby placing marginalized groups at the center of numerous research and policy contexts (Berry et al., 2014; Schoenfeld, 2004; Stinson and Bullock, 2012). Inclusive mathematics education faces several challenges. These include demographic factors such as large student-teacher ratios, technological barriers evidenced by slow internet connection, economic constraints due to insufficient budgets, and sometimes political challenges arising from sudden curriculum changes (Gándara and Mordechay, 2017; Mejía-Rodríguez and Kyriakides, 2022; Perera-Rodríguez and Moriña Díez, 2017).

The specific problem addressed by this study is the persistent difficulty in implementing inclusive mathematics education due to the inherent nature of the discipline, such as its high degree of abstraction and dense symbolism (Mutodi and Mogege, 2021; Rubenstein and Thompson, 2001). While collaborative partnerships between general mathematics teachers and special education (SPED) teachers are viewed as a powerful solution to these complex issues (Ní Bhroin and King, 2019; Pozas and Letzel-Alt, 2023), the success of these partnerships depends heavily on the teachers' mental models of collaboration (Toikka and Tarnanen, 2022). These internal frameworks, built on prior experiences and assumptions (Mathieu et al., 2000; Moseley et al., 2010), significantly influence a teacher's willingness to engage in the very collaborative activities necessary to improve student outcomes (Tarnanen et al., 2021). Studying both the process and results of collaboration between teachers and other stakeholders can provide significant input in designing professional development activities that could nurture the collaborative skills of both in-service and preservice teachers. Furthermore, examining mental models of collaboration may help educational leaders and teacher preparation institutions optimize teachers' ability to improve educational outcomes (Tarnanen et al., 2021).

## 1.1 Teachers' mental models of collaboration

Scholars have shown that mental models could influence how individuals interpret, understand, and interact with people, events, actions, and the general world (Rouse and Morris, 1986; Senge et al., 2012). Other studies further showed that individuals may have a few conflicting mental models at the same time (Norman, 1983) without being aware of the effects on their behavior of such conflicts (Mevorach and Strauss, 2012; Senge et al., 2012). Other researchers have also noted that mental models are often incomplete, and individuals tend to selectively perceive and remember information that aligns with their existing mental models, potentially leading to biased interpretation and decision-making (Norman, 1983; Senge et al., 2012). Previous studies (Carroll and Olson, 1988; Rouse and Morris, 1986) have further suggested that mental models help individuals understand and interact with their environment. They allow people to describe the purpose and structure of their environment or organization, explain its functioning, and predict future trends (Jones et al., 2011; Mevorach and Strauss, 2012). Understanding how teachers view collaboration can help us explain their (un)willingness to participate in collaborative programs (Toikka and Tarnanen, 2022). These mental models can also provide information on the forms, processes, and types of collaborative activities relevant to teachers (Mevorach and Strauss, 2012). Several studies in the educational context revealed that aside from content knowledge, mental models also play significant roles in driving teachers' instructional practices, specifically guiding them in their actual teaching and everyday instructional decisions and actions (Haim et al., 2004; Jones et al., 2011; Mevorach and Strauss, 2012; Senge et al., 2012).

Several studies on the teachers' mental models of collaboration highlighted a persistent gap between the ideal and the reality (Abu-Alghayth, 2024; Kotilainen et al., 2025; Toikka and Tarnanen, 2022). Too often, teachers' deep-rooted, often unexamined beliefs lead them to practice cooperation—functional, short-term aid focused on logistics or sharing materials—rather than engaging in a deeper level of collaboration (Toikka and Tarnanen, 2022). This deeper level, which involves shared responsibility for student outcomes, joint planning, and reciprocal feedback on teaching methods, is hindered by several dominant mental models (Abu-Alghayth, 2024; Kotilainen et al., 2025). These include the individualistic culture of teaching, which centers on the traditional practice of teachers working autonomously in their own classrooms. This isolation may result from either teacher preference or organizational conditions. Hargreaves (1994) identified three variations: *elective individualism*, where teachers simply prefer to work alone; *strategic individualism*, where a teacher views working independently as the most effective way to manage their duties; and *constrained individualism*, where the organization's structure or conditions force or encourage teachers to maintain isolation. García-Martínez et al. (2021) also documented that the key challenges to developing teachers' collaboration involve teachers' unwillingness to share practices, their low levels of engagement, and the shortcomings in current teacher professional training on how to collaborate.

## 1.2 Meanings, models, and quality of collaborations

Considering the diverse definitions, components, and influencing factors of collaboration, it is essential to examine the varying models of collaboration that have changed over time. Understanding these models can help us better comprehend the intricate relationships and interdependencies among the various elements and factors involved in collaboration. This information can provide an overview of the current nature, strengths, and challenges of collaboration. The same information can also play a significant role in guiding education practitioners in planning, implementing, monitoring, and evaluating collaborative initiatives. Currently, collaboration is considered a multifaceted concept. Table 1 summarizes some of the evolving approaches to collaboration (intradisciplinary, multidisciplinary, and transdisciplinary) with corresponding columns on different meanings emphasized by sources in the first column.

The second column focuses on specific activities since collaboration can also encompass the embodiment of social, cultural, and structural constructs that respect the diverse roles and skills of each involved member (Welch and Tulbert, 2000). Each approach to collaboration has a distinct focus in terms of activity implementations. The intradisciplinary approach fosters innovation by bringing together professionals specializing in the same field (Bruer, 2005; Ma et al., 2018; Pimmer et al., 2012). In contrast, the multidisciplinary approach prioritizes clear communication and well-defined roles within a team (Masters et al., 2013; Strachan et al., 2023). Lastly, the transdisciplinary approach emphasizes the pooling of expertise from different fields to generate larger ideas (Daneshpour and Kwegyir-Afful, 2022; Hernandez, 2013; Klein, 2018). Furthermore, Gräsel et al. (2006) classified these collaborative activities into three levels: exchange, division of work, and co-construction. Exchange, being the lowest level, involves sharing information or knowledge. Division of work entails a joint goal and shared tasks, with individual contributions combined to form a collaborative team's outcome. Co-construction, being the highest level, involves partners working together concurrently until task completion.

The third column refers to the collaboration structure, which can be composed of individuals from similar or different fields working together to achieve mutually agreed-upon goals (Carrea et al., 2005; Snell and Janney, 2005). In terms of structure, the intradisciplinary approach to collaboration expects all team members to be knowledgeable and skilled in the shared standards and procedures that guide their work (Bruer, 2005; Ma et al., 2018; Pimmer et al., 2012). The multidisciplinary approach emphasizes regular meetings and the use of various communication channels while maintaining flexibility within the team (Masters et al., 2013; Strachan et al., 2023). Lastly, the transdisciplinary approach prioritizes the development of broad intellectual frameworks over specific disciplinary knowledge, aiming to create transferable skills and knowledge applicable across various fields of work (Daneshpour and Kwegyir-Afful, 2022; Hernandez, 2013; Klein, 2018).

Finally, the fourth column refers to the goals of these models, where collaboration is viewed as a reflection of members' values, roles, and skills (Rainforth and England, 1997; Welch, 1998). In the field of education, collaboration is widely recognized as a key characteristic of effective working relationships among individuals providing education and related services within the educational setting (Stephanie, 2010; Utley and Rapport, 2002). Similarly, each approach to collaboration has a unique focus in terms of its goals. The intradisciplinary approach relies on a team of experts within the same field working together toward a shared objective (Bruer, 2005; Ma et al., 2018; Pimmer et al., 2012). On the other hand, the multidisciplinary approach aimed to benefit from the diverse viewpoints offered by different fields of study (Masters et al., 2013; Strachan et al., 2023). The transdisciplinary approach prioritizes open communication and shared responsibility among team members (Daneshpour and Kwegyir-Afful, 2022; Hernandez, 2013; Klein, 2018).

The meanings and approaches to collaboration presented in Table 1 can serve as a guide for educators on how to collaborate effectively to achieve positive outcomes for all learners. However, it is important to note that these models may need to be adapted to suit specific organizational and cultural contexts. Therefore, local education practices, as well as community resources and educational objectives, should be considered when implementing or combining these models. As collaboration is becoming increasingly important in education (Ghedin, 2021), it is crucial to encourage new practices that foster collaboration among education stakeholders, such as general education teachers, SPED teachers, and other allied professionals.

**TABLE 1** Meanings and approaches to collaboration.

| Sources | Approaches | Activities | Structures | Goals |
|---|---|---|---|---|
| Bruer, 2005; Gräsel et al., 2006; Ma et al., 2018; Pimmer et al., 2012 | Intradisciplinary approach | Encourages innovation in a certain field since it brings together professionals in the same field.<br>Level: exchange of ideas | All members of the team belong to the same area of expertise and are knowledgeable and skillful on the standards and procedures to be followed. | Work toward the achievement of a common goal. |
| Gräsel et al., 2006; Masters et al., 2013; Strachan et al., 2023 | Multidisciplinary approach | Effective communication among team members, strong leadership and management skills, a trusting environment, shared expectations, and clearly defined roles and responsibilities.<br>Level: division of work | Collaborators prepare for regular meetings and utilize various communication channels while maintaining flexibility. | Highlight the unique perspectives that different disciplines can bring to illuminate a theme, subject, or topic. |
| Daneshpour and Kwegyir-Afful, 2022; Gräsel et al., 2006; Hernandez, 2013; Klein, 2018 | Transdisciplinary approach | Members offer their expertise to contribute to the larger ideas of the group.<br>Level: Co-construction | Prioritizes the development of broad intellectual frameworks over specific disciplinary knowledge, aiming to create transferable skills and knowledge that can be applied across various fields of work. | Emphasize the importance of information sharing and mutual responsibility among team members. |

## 1.3 Collaborations between mathematics and special education teachers

In the past, discussions on the issues of inclusive education have been dealt with mainly in the field of SPED (Scherer, 2019). There has been a growing number of studies (Bruggink et al., 2013; Tomlinson et al., 2003; Ysseldyke, 2005) documenting the increasing responsibility given to general education teachers in providing quality education based on the needs of individual students. For example, mathematics teaching poses unique challenges due to its high degree of abstraction and dense symbolism (Mutodi and Mogege, 2021; Rubenstein and Thompson, 2001). Concepts are not merely descriptive; they are encoded in a symbolic language that requires significant cognitive processing to decode and apply (Castro et al., 2022). For CSENs, these symbols can become barriers to conceptual understanding rather than tools for it (Videla et al., 2025). Furthermore, the cumulative knowledge structure of mathematics means that learning is strictly hierarchical (Verschaffel et al., 2010). Each new concept is built upon the mastery of previous ones. When a student struggles with foundational abstraction, the "cumulative deficit" grows exponentially, making subsequent topics increasingly inaccessible (Ten Braak et al., 2022). This "wall of abstraction" is where the expertise of a single teacher often reaches its limit.

The relevance of the collaboration between mathematics and SPED teachers is found precisely at this intersection of content and accessibility. Currently, further research is still needed on how both SPED and discipline-specific teacher education can take part in these discussions. For example, mathematics teachers must be aware that contextualized pedagogy is appropriate for a classroom composed of diverse groups of learners. However, without formal SPED training, it will be challenging for mathematics teachers to acquire sufficient knowledge and skills to address the educational needs of every learner. The mathematics teacher can provide the disciplinary depth necessary to navigate the cumulative curriculum, while the SPED teacher can help facilitate the pedagogical scaffolding required to deconstruct complex symbolism and abstract theories. In this case, letting mathematics teachers work collaboratively with SPED teachers should benefit both the student and the teacher's personal and professional development in terms of delivering inclusive and quality mathematics education. This collaboration is essential to ensure that "inclusion" is not merely physical presence in a classroom, but a cognitive access to the curriculum as well. Additionally, since pre-service teachers in mathematics often have limited exposure to diverse learners, the knowledge and skills they acquire from their teacher education programs may take time to be fully integrated into their teaching practice. Further, pre-service SPED teachers may have limited experience in specific pedagogical content areas.

## 1.4 LS as a means for teachers' collaboration

Engagement in collaborative teacher professional development programs, such as in Lesson Study (LS), allows the sharing of experiences and knowledge between teachers and can thus moderate the isolation of teaching from other learning support services. Thus, LS can be considered as one of the suitable approaches to provide general and SPED teachers an opportunity to deepen their pedagogical content knowledge as well as equip them with strategies on how to encourage learning among a diverse and challenged group of learners (Dudley et al., 2019; Cheung and Wong, 2014; Verhoef et al., 2014). Indeed, teachers' discussion, reflection, and dialogue processes (e.g., LS) will redound to their better understanding of educational concepts such as curricula, inclusions, collaborations, innovations, and classroom practices. Currently, there is a long-standing interest in utilizing LS as a collaborative technique to enhance teaching practices in various disciplines, predominantly in science and mathematics education (Fernandez, 2002a; Lewis, 2002; Miller-Young and Yeo, 2015; Peter, 2013; Stigler and Hiebert, 1999). However, little research explores how to involve pre-service teachers in collaborative working modes with in-service teachers (Tan et al., 2024), particularly in creating inclusive learning environments.

Thus, considering the roles of subject teachers and SPED teachers, it would be beneficial to create opportunities for in-service and pre-service teachers in SPED and specific disciplines (e.g., mathematics) to discuss ideas and collaborate on implementing and evaluating innovative educational solutions. Hence, this study examined this research question: In what ways do existing and emerging mental models of collaboration, held by preservice and in-service mathematics and SPED teachers, change through experiences in LS implementations? By pairing mathematics and SPED teachers, the present study investigates a "hybrid" instructional space. This means that the focus is not just on how to teach math, but on how two different professional cultures (one rooted in disciplinary rigor and the other in individualized scaffolding) negotiate the barriers of mathematical abstraction and symbolism. This study also moves beyond behavioral analysis by focusing on the underlying mental models of the participants. Rather than merely documenting what teachers do during LS, this research explores how the LS process facilitates a fundamental shift in these internal frameworks.

# 2 Materials and methods

This study gathered data through key informant interviews and document analyses. This data collection was conducted before, during, and after the implementation of the four LS cycles participated by preservice, in-service, math, and SPED teachers. The following subsections detail the selection of participants and study sites, data collection, and analysis methods employed in this study. These subsections also include discussions on how the ethical, reliability, and validity concerns were addressed.

## 2.1 Participants

This study focused on preservice and in-service teachers in middle schools (years 7–10) implementing inclusive mathematics education practices in Naga City, Philippines. In selecting study sites, the researchers employed a multi-step nomination and screening process. This process involved the formulation of criteria for selecting study sites, which include schools (i) accommodating children with special educational needs (CSENs), (ii) with available SPED teachers, (iii) implementing inclusion for more than 1 year,

TABLE 2 Type and distribution of participants.

| Type of participants | Distribution of participants | | |
|---|---|---|---|
| | LS team A | LS team B | Total |
| Preservice mathematics teachers | 2 | 2 | 4 |
| Preservice special education teachers | 2 | 2 | 4 |
| In-service mathematics teachers | 2 | 2 | 4 |
| In-service special education teachers | 2 | 2 | 4 |
| Total | 8 | 8 | 16 |

and (iv) having made adequate yearly progress in students' math performance for the last 3 years based on the National Achievement Test (NAT) results. The researchers sought recommendations from university professors and education supervisors in mathematics or SPED to identify the initial list of potential study sites. These recommendations were also based on the criteria outlined above.

Grounding on the multi-case study and time-series design (Gasparrini, 2021; Greene and David, 1983), the participants in this study were not randomly assigned. Instead, the participating teachers were purposefully selected to provide information essential to address the stated research objective. Specifically, the units studied are in-service and preservice teachers specializing in mathematics or SPED. The selected participants are situated within a dual-educational ecosystem in Naga City, Philippines, comprising two public secondary schools and a leading teacher education institution in the city. The in-service participants were veteran educators who had taught at the selected study sites between 5 and 20 years; this longitudinal experience ensured that they possessed a deep-seated understanding of the schools' inclusive mathematics practices and national achievement test performance trajectories. Parallel to this, the pre-service participants were drawn from a teacher education institution recognized for its programs in Mathematics and SPED. In the Philippines, discipline-specific teachers are not required to attend courses on SPED during their preservice education. In the same manner, SPED teachers are also not required to attend preservice discipline-specific courses. Participants in this study consisted of the experimental groups identified in the authors' previous research (Basister et al., 2025b). In this broader investigation (Basister et al., 2025a,b), a sample size of eight members per group was established through an *a priori* power analysis using G*Power 3.1 (Kang, 2021). As shown in Table 2, this study consisted of two teams, each comprising eight preservice and in-service teachers in mathematics or SPED.

## 2.2 LS implementations

The formation of the LS teams occurred within the scope of a broader investigation (Basister et al., 2025a,b). This larger study was dedicated to examining how preservice and in-service teachers collaborate, specifically those specializing in mathematics or SPED. Both LS teams first received training on the LS process, covering its aims, benefits, and inherent challenges. Each team conducted four LS cycles between January and April 2024, following the standard LS model defined by Stigler and Hiebert (1999). Each cycle was a collaborative and iterative process encompassing joint planning, lesson delivery, observation, post-lesson reflection, revision, and re-implementation. Specifically, each cycle included two planning sessions resulting in two co-authored lesson plans; two deliveries where one teacher taught the lesson while other LS team members observed and recorded feedback; two post-lesson conferences to revise the lesson plan and materials; and the subsequent re-implementation of the revised lessons. Each LS cycle was conducted over a 3–4-week timeframe, allowing sufficient intervals for planning, implementation, observation, shared reflection, and re-implementation.

Scholars (Kager et al., 2024) used the term "research lesson" for the collaboratively planned and refined lessons during LS cycles. In this study, these "research lessons" were implemented in middle school classrooms (years 7–10) with diverse student populations, including CSENs such as those with autism, learning disabilities, and intellectual disabilities. As a team, the participating teachers selected the lesson topics (e.g., radicals, exponents, and statistics) based on students' prior performance, demonstrating a teacher-driven approach to addressing specific pedagogical challenges. The four LS cycles implemented by the two LS teams covered core mathematical competencies. For LS Team A, the research lessons focused on exponents, parallelograms, circular permutations, and quartiles. Meanwhile, LS Team B addressed mathematical variations, tangents, secants, and the graphing of circles. Additionally, during lesson deliveries and observations, the LS team members used observation forms to record their comments and suggestions on the teaching and learning process. This structured observation tool enabled participants to document lesson implementation with their qualitative insights into instructional methods, student interactions, and real-time adaptations. It further utilizes a spatial observation map to visually document classroom dynamics and the flow of engagement during the instructional delivery. The first author also completed a research diary based on his observations of all the stages of the four LS cycles implemented by both LS teams. With participant permission, all stages of LS cycles, such as collaborative lesson planning, lesson deliveries, and post-lesson conferences, were recorded and transcribed.

## 2.3 Data collection

Before data collection commenced, the researchers obtained approval from the UPLB Research Ethics Board (REB). Informed consent was also obtained from each participant after they were informed about the nature and purpose of the study, their potential role, the researchers' identity, the funding source, and how the research findings would be used. To address the research objective, the researchers analyzed LS materials and relevant education policies and also conducted key informant interviews before and after the LS cycles. The data collection ran for 8 months, specifically from November 2023 to June 2024. The first author conducted interviews before (November–December 2023) and after (May–June 2024) the LS cycles. The document analyses were conducted during LS cycles (January–April 2024).

The two LS teams served as multiple cases for this study, providing opportunities to corroborate, qualify, or extend findings. As emphasized by scholars (Bonett, 2012; Halkias et al., 2022), findings in multiple cases can confirm, replicate evidence, and support the extension of prior research results. All selected participants ($n$ = 16) voluntarily joined the pre- and post-LS cycles interviews personally conducted by the first author. Each interview lasted an average of 60 min. Semi-structured interviews with key informants were utilized since this method facilitates access to information through words and non-verbal cues from the participants (Stake, 2010). This also provides opportunities for researchers to gather the perspectives of the participants and describe their mental models of collaboration before, during, and after the conduct of the four LS cycles. The process of developing and finalizing the interview guides was a meticulous, multi-step process undertaken with the specific goal of eliciting responses to address the objectives of this study. This began with a review of relevant literature concerning teachers' collaborations and mental models, followed by an inductive thematic analysis to establish key themes and codes. Ultimately, the guides were rigorously validated by experts who are significant figures in the fields of either inclusive education or mathematics education, ensuring their academic soundness and relevance. The questions from the semi-structured interviews revolved around (i) teaching and learning, (ii) classroom-related tasks, (iii) collaborations, (iv) professional development activities, and (v) school as a work community. With the consent of the participants, all interview proceedings were audio recorded to enhance data reliability and to facilitate triangulation, iteration, and repeated analyses of collected data.

The researchers also utilized a comprehensive set of documents from the LS cycles to supplement the key informant interviews. This document analysis included copies of the jointly prepared lesson plans, the lesson observation forms completed by participants, transcripts from both collaborative lesson planning and post-lesson conference proceedings, and memoranda from education departments. In total, the document analysis drew from a significant body of data: eight collaborative lesson planning transcripts, eight jointly prepared lesson plans, 48 completed observation forms from LS members, 16 post-lesson conference transcripts, 16 post-LS interview transcripts, four memoranda from basic and higher education departments, and the first author's research diary.

## 2.4 Data analysis

Without distorting scholarly meanings, the data from key informant interviews and document analyses were anonymized, transcribed, and coded to facilitate the development of themes, categories, and sub-categories. These were used to build initial descriptive narratives of the teachers' mental models of collaboration. Specifically, three phases of evidence-based, theory-informed content analyses of collected data were conducted to describe the teachers' mental models of collaboration (DeCuir-Gunby et al., 2011). The combined approach of using evidence-based, yet theory-informed, content analysis was followed to ensure that this study is both rigorous and relevant. The evidence-based aspect guarantees objectivity, requiring researchers to ground their analysis in verifiable data drawn directly from documents and transcripts, which minimizes bias and enhances the reliability and transparency of the findings (Krippendorff, 2019). Conversely, the theory-informed element provides the necessary conceptual lens, offering a framework to guide what themes to look for (see Table 1) and, crucially, to move beyond simple description to meaningful explanation (Patton, 2015). By linking observed evidence to established academic theories, this method allowed researchers to interpret why certain phenomena occur and to generalize their findings, thereby enriching the overall academic conversation and maximizing the external validity of the study (Hsieh and Shannon, 2005; Krippendorff, 2019; Patton, 2015).

The first phase of the content analysis conducted involved coding based on in-depth reading of the transcribed interviews and other relevant documents. The initial codes were carefully checked for coding logic and discrepancies to ensure data validity, consistency, and agreement. Specifically, the first phase of analyses relied on the three-part description of mental models to define, explain, and predict the teachers' representations of collaboration (Rouse and Morris, 1986). More specifically, these three dimensions include: (i) how they articulate the core purpose and structure of teachers' collaboration, (ii) how they explain its current systemic operations and conditions, and (iii) how they forecast the future state of teachers' collaboration. The first two dimensions provide complementary insights into the current collaborative practices, while the third is dedicated to its prospective future. The second and third phases of content analyses were anchored on the evolving models and meanings of collaborations, as summarized in Table 1. Particularly, the second phase involved reviewing the resulting codes to develop initial themes, categories, or subcategories representing teachers' mental models of collaboration in terms of collaborative activities, structure, and goals. For instance, the statement from mathematics teachers that the presence of "the SPED teachers provided significant information on how to design materials and implement strategies suited to the needs of CSENs present in the class" was coded as "collaboration with members having various specializations." Furthermore, the codes related to "collaboration with members from the same field," "collaboration with members having various specializations," and "collaboration with other stakeholders," were grouped under the "structure" of collaboration. The third phase involved within-case and cross-case analyses to compare codes, themes, and categories describing the teachers' mental models of collaborations before and after the four LS cycles. At this stage, the research team focused on detailing code definitions and extracting subordinate themes. To guarantee an accurate representation of the data, all developed themes and categories were cross-checked against the raw data. Furthermore, each theme was clearly named, defined, and supported by illustrative quotes. Trustworthiness was enhanced by having the research team actively discuss and resolve any discrepancies in coding or interpretation until full agreement was achieved. This cyclical process of comparing themes to the data continued until thematic saturation was reached (Rahimi and Khatooni, 2024), signifying that the analysis had generated a comprehensive understanding of the teachers' mental models of collaboration.

# 3 Results

Using appropriate extracts from the collected data, the following subsections show how the participants described their existing and emerging mental models of collaboration. Grounding on ideas summarized in Table 1, these mental models were illustrated based on the evolving approaches to collaborations and the corresponding activities, structure, and goals of these models.

## 3.1 Activities

The subsections below describe the collaborative activities that transpired during document analyses and interviews conducted pre- and post-LS cycles. These activities integrate social, cultural, and structural elements in a way that values the unique roles and abilities of each person involved. In the interviews conducted before the introduction of LS, the participants shared that some of their collaborative practices include class observations, learning action cells, field studies, and teaching internships. In the interviews conducted after experiencing the conduct of LS, the participants shared additional collaborative activities such as collaborative lesson planning, joint class observation, post-lesson conferences, team teaching, and profiling of students.

### 3.1.1 Class observations

The interviews with LS team members conducted before the LS cycles revealed that class observation is one of the most common collaborative activities in the participants' respective schools. However, the participants disclosed that this is usually conducted between teachers and educational leaders (school principals, head teachers, master teachers), with the latter as the observer. As elaborated by one participating in-service math teacher (IMT) during pre-LS interviews, the usual practice of the education leaders is to check first the lesson plans of the delivering teacher before conducting a class observation.

> *"This is to provide appropriate suggestions, if any, that could contribute to the improvement of the lesson before its delivery."* (IMT2)

> *"During class observations, the school principals, head teachers, or master teachers utilized observation tools prescribed by the education department to guide their observations."* (IMT1)

Based on document analyses of relevant education department issuance (Republic of the Philippines Department of Education, 2023), the set of indicators in the observation form utilized by education leaders varies per quarter. There is a total of nine indicators in the prescribed tool, and the education leaders are only focusing on six of these indicators per quarter during class observation. Analyzing further the education department issuance relevant to conducting class observations (Republic of the Philippines Department of Education, 2023), these indicators cover various areas such as (i) knowledge and skills of teachers on content of and teaching strategies for their field of specialization and other disciplines; (ii) proficiency in using mother-tongue, Filipino, and English language to facilitate teaching and learning processes; (iii) establishing safe, secure, leaner-centered, and culturally sensitive learning environments, and (iv) providing accurate, timely, and constructive feedback to improve learners' performance.

Other participants further shared during pre-LS interviews that after the conduct of class observation, a post-conference between the delivering teacher and the educational leader who observed the lesson delivery is usually held to discuss the strengths and areas for improvement of the conducted lesson. The participating in-service math teachers and SPED teachers (IST) both shared that during post-conferences, they *"discuss the best part of the lesson,"* (IMT1*)* *"the part that needs to be improved,"* (IST4), and *"the strategies on how these parts can be improved."* (IMT3)

### 3.1.2 Learning action cells

The interviews conducted before LS also revealed the learning action cell sessions as another existing collaborative practice. Based on document analyses of the relevant department issuance (Republic of the Philippines Department of Education, 2016), these sessions are a nationwide initiative institutionalized by the Philippines' Department of Education. Each learning action cell comprises teams of teachers who collaborate to address shared challenges within their schools. The implementation of learning action cells typically involves several steps, including needs assessment, agenda prioritization, team formation, resource identification, and the implementation and evaluation of agreed-upon interventions. As stipulated in the department issuance, the learning action cell sessions may include lectures, practicums, orientations, coaching, workshops, and the development and utilization of instructional materials. Two participating in-service teachers also shared that

> *"the learning action cell sessions allowed us to develop interventions in various forms"* (IMT4), *"such as learning materials, instructional materials, equipment, facilities, teaching strategies, teaching modalities, or educational programs."* (IMT2)

### 3.1.3 Field studies and teaching internships

Interviews conducted before LS implementations also revealed the existing collaboration between preservice and in-service teachers in the form of field studies and teaching internships. Document analyses of pertinent government issuance (FEU Public Policy Center, 2017) also showed that the Field Studies I and II courses for preservice teachers, along with Teaching Internships, are integral parts of Philippine teacher education. As outlined in the analyzed government memorandum, Field Studies I focuses on classroom observation and documentation. In contrast, Field Studies II involves classroom observations and limited participation in the teaching activities of in-service teachers. The same government memorandum further stipulated that the Teaching Internships culminate the field study experience, allowing preservice math teachers to assume full responsibility for teaching a class. The participating preservice math teachers (PMT) emphasized that

> *"with the help of our assigned cooperating in-service teachers, our field studies and teaching internship experiences provided opportunities for us to bridge the gap between theory and practice."* (PMT1).

> *"These field and internship experiences equip us with the necessary knowledge, skills, and dispositions to become effective educators."* (PMT4)

### 3.1.4 Collaborative lesson planning

The collaborative lesson planning between members showed exceptional attention to detail such as time allocation, assessing learners' initial knowledge, identifying and selecting lesson materials, and including the process of introducing these materials. During the lesson on zero and negative exponents (first LS Cycle), the way the LS team A designed the lesson assessment tool was contextualized based on students' abilities.

> IM1: *Let's try a different approach. Instead of giving them word problems to solve, let's see if they can construct their own problems that apply the laws of exponents.*

> IS2: *I'm on board with that. It's a great way to incorporate higher-order thinking skills while naturally allowing for differentiated instruction.*

> PS2: *That's a great idea. Just as a suggestion, we might want to start small—perhaps ask them to construct just one word problem so struggling learners don't feel overwhelmed.*

(Collaborative lesson planning transcript, 04 January 2024)

In the interviews conducted after experiencing LS implementations, participating preservice math teachers and SPED teachers (PST) both highlighted that collaborative lesson planning was beneficial for the improvement of the teaching and learning processes. These post-LS interviews further revealed that collaborative lesson planning during LS

> *"provided us opportunities to share"* (PMT3) and *"listen to ideas"* (PMT1) in *"producing engaging and appropriate learning activities and materials."* (PST1)

### 3.1.5 Joint lesson observations and post-lesson conferences

Except for the delivering teacher, all other members of each LS team are expected to observe the implementation of the research lesson. The focus of this observation is to study the reactions of the students during the lesson and determine the strengths and areas for improvement of the research lesson. Post-lesson conferences immediately follow the implementation of the research lesson. The LS team discussions during these post-lesson conferences were based on the observation of each member, and these discussions served as input for lesson revision and re-implementation.

The structured observation form used during joint lesson observations guided the LS team members to note real-time deviations from the prepared lesson plan. It provided the LS team members with the ability to objectively document the "what, why, when, and how" of instructional changes. As shown by the post-lesson conference transcript during LS Team B's first LS cycle below, this tool facilitated identification of specific "moments of (dis)engagement," fostering a data-driven basis for the post-lesson reflection.

> IM1: *Reflecting on the first cycle, it seemed the students weren't fully connected with the material. I think we should pivot toward using interactive games and collaborative tasks to boost their engagement levels.*

> IS1: *If we're going to bring in games, I think it would be more effective to use visually appealing materials that the students can actually get their hands on and move around.*

(Post-lesson conference transcript, 08 February 2024)

The following excerpt is drawn from the team's finalized observation reports compiled during the research lesson's second implementation:

> *"The lesson successfully captured the interest of the students, with particularly high levels of engagement observed among the learners with special needs."* (PS2, observation form notes)

> *"The instructional atmosphere shifted noticeably as the introduction of gamified elements and vibrant, tactile resources sparked an increased level of participation among the learners"* (PM2, observation form notes).

After attending LS implementations, one participating in-service teacher disclosed during interviews that her perception of classroom observations had changed.

> *"Before, my idea of classroom observation was just a tool for evaluating my performance. Now, I can see it as an opportunity to learn from the practices of other teachers."* (IMT3)

### 3.1.6 Team teaching

In one of the interviews conducted, one participant also mentioned the idea of team teaching to modify the flow of LS implementation. She specifically proposed that:

> *"the lesson delivery and observation part can still be modified where the LS team members will not just be observers but can also be part of the lesson implementation through assisting in the preparation of lesson materials and in the actual conduct of lesson activities."* (PMT3)

### 3.1.7 Profiling of students

An in-service math teacher also suggested that:

> *"LS activities can be utilized to profile the students, especially the CSENs."* (IMT2)

Further, the participating preservice and in-service math teachers explained that:

> *"as a math teacher, the involvement of preservice and in-service SPED teachers can provide significant information to us, especially on the characteristics of CSENs in our classes"* (IMT3), *"including the corresponding accommodations that can be made for CSEN students."* (PMT2)

Although all participants agreed that LS activities are generally beneficial for teachers and for the students as well, some of them raised particular concerns about LS implementations.

> *"I find it difficult to attend all of the LS activities since some of these activities coincide with my class or school activities."* (PST4)

> *"I noticed that some of the students are not comfortable having observers in the class. I believe they are more conscious about what they say during class activities."* (IMT1)

> *"Sometimes, I find it challenging to re-implement the revised lesson in another class since the comments and suggestions during lesson evaluation and revisions are not always applicable to another group of students."* (IMT4)

## 3.2 Structure

The collaboration structure considers the diverse backgrounds of team members, who may come from different fields. It emphasizes shared goals, effective communication, and flexibility. The focus might be on developing broad skills or including parents in decision-making. Additionally, it ensures all members understand and follow common standards and procedures. Considering the approaches to collaboration outlined in Table 1, the subsections below describe the existing (pre-LS) and emerging (post-LS) collaborative structures as perceived by the participating preservice and in-service teachers. In the interviews conducted before the introduction of LS, the participants shared that the structure of their collaboration is mostly with members from the same field. In the interviews conducted after experiencing the conduct of LS, the participants shared additional structures for collaborative activities, such as having members from different fields and even involving other education stakeholders.

### 3.2.1 Collaboration with members from the same field

The interviews and document analyses conducted before LS implementations showed that the existing collaborative activities involved preservice, in-service, and master teachers in the same field, in this case, mathematics or SPED. Specifically, interviews before LS cycles revealed that the class observations and post-conferences usually happen between in-service teachers and master teachers within the department. The participating in-service teachers shared that the master teachers have two functions when they observe classes.

> *"One function was coaching and mentoring on pedagogical content knowledge through observing classes and following up through post-conferences."* IMT3

> *"Another function was to, during class observations, rate the performance of the teachers based on the standards defined by the education department."* IST1

In some instances, the head teacher or the school head occasionally conducts class observations together with the master teachers. However, one of the participants shared that when having more than one observer in her class

> *"I encountered diverse and sometimes conflicting ideas on how to improve my lessons."* (IMT2)

In other collaborative activities, such as field studies and teaching internships, the analyses of a government document (FEU Public Policy Center, 2017) showed that the field of specialization is considered in the pairing of preservice and in-service teachers. The same government issuance emphasized that the field studies aimed to provide preservice teachers with practical experiences in real-world educational settings through observing and assisting in the classroom activities of assigned in-service teachers. On the other hand, interviews with preservice teachers before LS cycles showed that the teaching internships involved a semester-long experience where they were assigned to a cooperating in-service teacher in a selected school. The preservice teachers further shared that during teaching internships

> *"we observed experienced teachers, assisted in classroom activities, and gradually took on independent teaching responsibilities."* (PST3)

> *"these hands-on experiences under the guidance of my cooperating in-service teacher helped me develop essential skills such as classroom management, effective communication,"* (PMT4) and *"critical thinking, which I believe are crucial for a successful career in education."* (PMT1)

### 3.2.2 Collaboration with members having various specializations

Based on the analyses of a document relevant to learning action cell implementations (Republic of the Philippines Department of Education, 2016), a school may form several learning action cells that can be composed of teachers from the same department or teachers from various departments. Typically, each learning action cell has a leader (school head), a facilitator (could be school head, head teacher, or master teacher), a documenter (any member), and members (in-service teachers). External experts may be invited when needed, although the preference is to draw upon the expertise of the learning action cell members themselves. One participating in-service teacher shared that

> *"our cycles of observation, reflection, and experimentation within the learning action cell helped us improve our teaching practices."* (IMT4)

Below was the conversation between mathematics and SPED teachers during the third LS cycle when the LS Team A refined the research lesson about circular permutations.

> IM1: *I noticed that the vibrant, tangible learning materials we used successfully engaged the students.*

> IS2: *Mapping algebraic symbols onto physical items was particularly effective for struggling learners, as it allowed them to track conceptual changes through physical transitions.*

> IS1: *I agree on the use of authentic manipulatives. I am just concerned about the size of these manipulatives, which could be a limiting factor.*

> IM2: *In that case, I think we can just utilize students themselves as human manipulatives to represent mathematical objects. I believe this will further increase students' engagement.*

(Collaborative lesson planning transcript, March 19, 2024)

During post-LS interviews, the participants shared their openness to collaborating with teachers having different specializations. Specifically, the participating preservice and in-service math teachers welcomed the participation of preservice and in-service SPED teachers. In the interviews conducted after LS implementations, they specifically shared that

> *"the presence of preservice teachers allowed us to discuss ideas, strategies, and learning resources that are more relevant and well-suited to younger generations."* (IMT1)

> *"during LS activities, the SPED teachers provided us significant information on how to design materials and implement strategies suited to the needs of CSENs present in our class."* (PMT1)

### 3.2.3 Collaboration with other stakeholders

In interviews conducted after experiencing four LS cycles, some participants shared that other education stakeholders can also be involved in future LS implementations.

> *"I think we can involve teachers from senior high schools,"* (IMT1) *"from other disciplines,"* (IMT2) *"other schools in the district,"* (IST3) *"parents,"* (PST1) and *"other education leaders such as education supervisors."* (IMT4)

## 3.3 Goals

This subsection focuses on the common goals of the participants in their respective schools' collaborative engagements. In the interviews conducted before the introduction of LS, the participants shared their experiences in various collaborative activities and revealed that their reasons for joining these activities were to evaluate teachers' performances, benchmark the practices of their colleagues, and discuss numerous strategies in teaching mathematics. In the interviews conducted after experiencing the conduct of LS, the participants shared additional reasons for collaborative activities, such as joint preparation of teaching and learning materials and promoting an inclusive learning environment.

### 3.3.1 Performance evaluation

During pre-LS interviews, an in-service teacher shared that one of the goals during their collaborative practices is the evaluation of their teaching performances through the scheduled classroom observations conducted by master teachers, head teachers, or school heads. He further shared that

> *"classroom observations are conducted at least every quarter for every teacher with the aim of monitoring and assessing our teaching performances."* (IST4)

Although the main objective of the class observations is to assess the performance of the teachers, some participants claimed that

> *"I learned from the comments and suggestions given during post-conferences,"* (IMT1) *"we were given opportunities to reflect and examine our teaching practices,"* (IST3) and *"I became more aware of the areas for improvement in my teaching practices and managing classrooms."* (IMT2)

### 3.3.2 Benchmark teaching practices

All four participating preservice teachers shared that their involvement in collaborative activities in schools provided them with an opportunity to benchmark the teaching practices of in-service teachers. Specifically, in the conducted pre-LS interviews, preservice math teachers recalled that

> *"through observing in-service teachers during my field studies and teaching internships, it is possible to learn new and easier techniques in helping students learn mathematics lessons."* (PMT4)

> *"in addition to my preservice courses, the teaching internship afforded me opportunities to learn inclusive teaching strategies in diverse mathematics classrooms."* (PMT3)

> *"discussions with and benchmarking on the teaching practices of in-service teachers could help us improve our knowledge and skills in various aspects of teaching, such as lesson planning,"* (PMT1) *"development of learning materials,"* (PST3) *"lesson delivery, and assessing the performance of students."* (PST2)

> *"As a preservice teacher, it was a fulfilling experience to interact with the teachers in the field and clarify some of the questions we have in mind about situations,"* (PMT2) *"practices,"* (PST1) *and "challenges inside the classroom."* (PMT3)

### 3.3.3 Discuss teaching strategies

When participating in collaborative activities such as class observations and post-conferences, the participants explicitly stated during pre-LS interviews that discussing strategies for effective teaching was their primary goal. These discussions include analyses of the strengths, weaknesses, and impact of specific strategies on the teaching and learning processes.

> *"we discuss what is the best strategy in teaching a particular topic,"* (IMT3) *"I believe that it is healthy to collaborate with other teachers to learn and upgrade our skills in delivering lessons,"* (IMT1) *"as well as managing our classes."* (IMT4)

The teachers' participation in LS implementations provided additional opportunities to receive and provide inputs to further improve these teaching strategies. In one of the interviews conducted after LS cycles, the in-service math teachers specifically recalled that

> *"during LS implementations, I felt that there was an improvement in how I delivered the lessons and managed my classes"* (IMT2) *"as shown by the positive reactions and engagements of my students during lesson implementations."* (IMT1)

### 3.3.4 Co-creation of lesson materials

In an interview after the four LS cycles, two preservice teachers shared that

> *"through LS involvement, I discovered the new technique in teaching specific lessons which are different from the one discussed during our preservice courses"* (PMT3)

> *"I believe that our collaboration with in-service teachers could be enhanced more through our active engagement in the preparation of teaching and learning materials."* (PMT2)

Similarly, in the interviews conducted post-LS cycles, in-service teachers also recounted that

> *"the collaboration with preservice teachers provides us with opportunities to apply new trends in designing and utilizing educational materials they learned from their preservice courses."* (IMT4)

> *"I believe that having preservice and younger teachers during LS is crucial in terms of additional ideas on how to integrate technology in the research lessons."* (IMT2)

### 3.3.5 Promote inclusive learning

The interviews conducted after LS cycles further revealed the experiences of the participants during LS implementations. Two in-service teachers shared that

> *"I became more interested in how the lessons accommodated the CSENs."* (IMT1)

> *"I became more focused on how the CSENs can be more engaged during lesson implementations."* (IMT3)

In other post-LS interviews, three preservice math teachers also shared that

> *"honestly, I don't have sufficient background in handling CSENs."* (PMT1) *"During LS implementations, I learned from the comments and suggestions of preservice and in-service SPED teachers to accommodate CSENs,"* (PMT2) *"it gives me the motivation to take courses related to inclusive education to understand better the nature of every learner."* (PMT4)

## 4 Discussion

This section delves deeper into the teachers' existing and emerging mental models of collaboration by analyzing the evident approaches to collaboration through the collaborative activities, structures, and goals presented in the previous section. As summarized in Table 3, the examination of collected data shows that there are differences in how the participants perceive collaboration before and after LS implementations.

TABLE 3 Teachers' mental models of collaboration before and after Lesson Study (LS) implementations.

| Aspects of collaboration | Before LS implementations | After LS implementations |
|---|---|---|
| Activities | •Class observations<br>•Learning action cells<br>•Field studies<br>•Teaching internships | •Collaborative lesson planning<br>•Joint lesson observation<br>•Post-lesson conferences<br>•Team teaching<br>•Profiling of students |
| Structures | •Collaboration with members from the same field | •Collaboration with members having various specializations<br>•Collaboration with other stakeholders |
| Goals | •Performance evaluation<br>•Benchmark teaching practices<br>•Discuss teaching strategies | •Co-creation of lesson materials<br>•Promote inclusive learning |

## 4.1 Reconfiguring activities from logistical efficiency to collective ownership

In terms of collaborative activities, the collected data shows that an intradisciplinary approach to collaboration is dominant before LS implementations. This is shown by the intradisciplinary activities such as field studies and teaching internships specified in the analyzed government issuance (FEU Public Policy Center, 2017). Additionally, the interviews with in-service math (IMT1, IMT2, IMT3) and SPED (IST4) teachers before LS cycles indicated that class observations in the study sites mainly involved teachers from the same field. Nonetheless, analysis of another document also suggests that a multidisciplinary approach to collaboration was used even before LS was introduced. This is supported by a department issuance (Republic of the Philippines Department of Education, 2016) detailing that learning action cell sessions shall involve teachers and experts from different fields alongside their specific roles during the sessions. Moreover, drawing on Gräsel et al.'s (2006) framework for collaboration, the findings also suggest that the quality of collaborative activities before LS implementation was limited. These activities lack deeper levels of interdependence, primarily focused on sharing ideas and planning teaching and learning activities. These findings align with previous research reports on the qualities of teachers' activities, emphasizing lower levels of existing collaborations among teachers (Bush and Grotjohann, 2020; Heldens et al., 2015; Toikka and Tarnanen, 2022).

However, after experiencing LS implementations, the collected data during and after four LS cycles showed that the emerging collaborative activities could be recognized as a transdisciplinary approach to collaboration. This was explicitly shown by how math (PMT1, PMT3, IMT3) and SPED (PST1) teachers shared their ideas during post-LS interviews when they worked together on lesson planning, observations, reflections, and revisions. As observed by the first author, the activities during LS implementations demonstrated a progression from mere idea sharing to joint goal setting and task division. Considering Gräsel et al.'s (2006) framework for collaboration, the authors interpreted this as a shift toward higher levels of collaboration. Specifically, the participants' emerging concept of team teaching (PMT3) and joint preparation of lesson materials (PMT2, IMT2, IMT4) further exemplify a high level of collaboration that can provide opportunities for team members to work together to achieve common goals. Similar to the study of Pellegrino et al. (2015), this study also demonstrated that LS between mathematics and SPED teachers could be utilized to promote both collaborative and inclusive practices among participants. This is implied by the participants' (PMT2, IMT2, IMT3) shift in focus from teachers to students, fostering a deeper understanding of the diverse needs of their learners.

The participants' initial mental models of collaboration, characterized by activities for logistical efficiency (mere idea sharing), represent a fragmented schema (McCarthy et al., 2021), where teachers view their expertise as parallel rather than integrated. The participants' LS experiences disrupted this by introducing "collective ownership" centered on student data rather than on teacher performance. By shifting the focus from "what I do" to "how students learn," the LS process created a state of cognitive disequilibrium (Lehman, 2012). For example, when participants were confronted with the specific cognitive bottlenecks of mathematics—such as disengagement during lessons involving abstract symbolism—their individual, compartmentalized mental models proved insufficient. The shift to co-creation was the cognitive solution to this tension, forcing the participants to reconcile their separate expertise into a unified instructional "third space." This "shift" is not merely a behavior change, but an accommodation of schemas where participating teachers move from viewing themselves as isolated experts to viewing their roles as professionally interdependent.

## 4.2 LS promotes transdisciplinary structure through reciprocal learning

The collaboration structures before LS implementations were primarily intradisciplinary, involving teachers from the same field. For instance, based on the analyzed document (FEU Public Policy Center, 2017), pre-service and in-service teachers' pairing during field studies and teaching internships were based on their specializations. However, there were occasional instances of multidisciplinary structures, such as when learning action cells were formed regardless of their specialization as specified in the analyzed government issuance (Republic of the Philippines Department of Education, 2016). After experiencing LS cycles, participants became more open to a transdisciplinary approach to collaboration. Unlike multidisciplinary work, where one expert "consults" the other, transdisciplinary practice involves role-release. Teachers developed a shared "mental model" where the responsibility for both mathematical rigor and student accessibility became inseparable. Additionally, the accounts from the participants (IMT2, PMT1) during post-LS interviews indicated that their LS experiences further enriched their existing idea of collaboration. These post-LS data further revealed that LS promotes collaborative inquiry, encouraging active participation of both preservice and in-service teachers in lesson planning, observation, and data-driven decision-making. Concurring with Baumfield et al. (2022), this study also showed that LS can facilitate the preservice teachers' integration of theory and practice, enhancing their specialized content knowledge and critical observation skills.

Additionally, whilst in-service teachers have greater potential to contribute to collaborative inquiry (Coenders and Verhoef, 2019), their LS experiences with preservice and other experienced teachers helped them identify and address ineffective teaching practices that they need to unlearn. This was specifically supported by the statement of in-service teachers (IMT1, IMT2) acknowledging the presence of preservice and other in-service teachers as essential in discussing ideas, strategies, and learning resources that are more relevant and well-suited to younger generations. Furthermore, one participant (PMT1) also emphasized that during LS activities, the ideas from preservice and in-service SPED teachers provided significant information on how to contextualize materials for CSENs. Similarly, by internalizing three different ways (concrete, representational, abstract) to model a mathematical concept during LS cycles, the SPED teacher (IS1, IS2) moves beyond general support to master specialized mathematical scaffolds. This clearly shows that the LS engagements employed in this study also allowed mathematics and SPED teachers to learn from each other, potentially leading to positive changes toward a more inclusive approach. This is similar to the findings of other scholars (Leatherman, 2009; Paulsrud and Nilholm, 2023; Pellegrino et al., 2015) in their studies, exhibiting that collaboration between regular and SPED teachers promotes inclusion.

A common tension in the literature is the perceived trade-off between mathematical rigor and inclusive scaffolding (Stein et al., 1996). The findings from this study offer a dialogic challenge to this binary. By identifying that a high-level task—such as student-led word problem creation—can simultaneously serve as a vehicle for differentiated instruction, the participants demonstrated that rigor and accessibility are mutually reinforcing. This also adds a new layer to the work of Wu and Liu (2024), suggesting that reciprocal learning is the mechanism that allows teachers to navigate this paradox. One illustration of reciprocal learning in this study is the collective identification of barriers during LS cycles. Specifically, when one SPED teacher (IS1) brings a lens of differentiated strategies by pointing out a physical limitation (the size of the manipulatives). This is a classic "inclusion" concern—ensuring that materials are accessible to all students, including those with fine motor or visual challenges. Instead of stalling the conversation, a mathematics teacher (IM2) provides a creative disciplinary solution (kinesthetic embodiment). By suggesting students become "human manipulatives," the math teacher scales up the lesson's visibility and engagement. This is the "third space" of collaboration—a solution that is both mathematically sound (representing variables) and pedagogically inclusive (removing the barrier of small materials).

## 4.3 Transformation of collaborative goals through cognitive syncretism

In terms of the participants' goals for collaboration, the data showed that before implementing LS, participants focused on an intradisciplinary approach to collaboration. As explicitly mentioned by participants (IMT1, IMT3, IMT4), their class observations and post-conferences before LS primarily focused on discussing their strategies with their colleagues in the same department. Additionally, the pre-LS intradisciplinary activities, such as field studies and teaching internships with in-service teachers, helped preservice teachers (PMT1-4, PST1-3) improve their knowledge and skills. This meant that before LS cycles, team members with similar expertise aimed to work together to improve their teaching practices by comparing their methods and discussing their strategies.

As shared by an in-service teacher (IST4) during pre-LS interviews, another goal of class observations is performance evaluation. These class observations typically involved teachers and educational leaders from the same field, but sometimes included teachers from different fields. In this case, the goal of evaluating teaching performance can be classified as both intradisciplinary and multidisciplinary. This approach highlights how different perspectives can improve teaching while emphasizing the importance of sharing information and working together (North et al., 2018). After experiencing LS cycles, the participants started collaborating more across different fields, as shown by their goals of co-creating educational materials (PMT2, PMT3, IMT2, IMT4) to promote inclusive classrooms (IMT1, IMT3). Through LS experiences, the participants (PMT1, PMT2, PMT4) also recognized the value of bringing together individuals from various fields, including teachers from other disciplines, SPED specialists, and even parents, to work toward common goals. While scholars such as Scherer (2019) emphasize the "holistic approach" of collaboration, the findings from the present study clarify the cognitive "how." The authors position these findings as a bridge between the social-collaborative focus of LS and the cognitive-psychological focus of teacher mental models. This suggests that the "innovation and creativity" lauded in prior research (Basister et al., 2025a; Kalyva, 2013) are actually the byproduct of schema accommodation, where teachers must dismantle their intradisciplinary biases to achieve a common instructional vision.

Furthermore, the shift in participants' goals from intradisciplinary observation to transdisciplinary co-creation represents more than a change in meeting structure; it signifies the emergence of cognitive syncretism (Gregory et al., 2013). Initially, the participants' collaborative mental models were rooted in intradisciplinary isolation, where expertise was viewed as a department-specific affair. Theoretically, this indicates a parallel schema (McCarthy et al., 2021), where the participating math and SPED teachers operate as distinct entities with separate goals, often resulting in a fragmented learning experience for the student. However, the participants' immersion in LS cycles catalyzed a shift toward cognitive syncretism—the mental fusion of diverse professional expertise to address the unique challenges of inclusive mathematics. This was evidenced by the transition in participants' goals from observing performance to co-creating educational materials. In this transdisciplinary phase, the participants' goals shifted from "refining my own teaching" to "collectively decoding the student's struggle." When participants recognized the necessity of involving SPED specialists and even parents to promote inclusive classrooms, they were no longer just sharing information; they were re-bordering their professional identities. This shift creates a "third space" of professional knowledge where mathematical rigor and pedagogical accessibility are no longer seen as competing interests, but as a single, syncretic objective. By moving toward this holistic approach, the collaboration transcends simple task division and enters a state of collective agency (Zhang and Zhang, 2025), which is essential for dismantling the complex barriers inherent in mathematics education.

## 4.4 Mental models as mediators of educational reform

It can also be noted that three participants raised concerns about the readiness, replicability, and sustainability of the LS cycles implemented. These concerns include time management (PST4), the preparedness of students (IMT1), and the replicability of research lessons (IMT4). This suggests that teachers encountered various challenges in collaborative environments, necessitating further exploration of opportunities to enhance collaboration. It is important to note that contradictory and resistant mental models can be valuable (Toikka and Tarnanen, 2022) and may indicate a need for deeper reflection and discussion. Theoretically, these findings also suggest that mental models are the primary mediators of educational reform. While the LS cycles provided the social structure for collaboration, the participants' internal frameworks provided the cognitive limit. The emergence of concerns regarding readiness, replicability, and sustainability indicates that the "shift" is a process of ongoing oppositions and negotiations (Capone et al., 2024). By making these mental models visible through reflection and discussion, educational leaders can target the underlying cognitive structures that either facilitate or resist inclusive practices. This moves teacher preparation beyond the mastery of individual performance toward the cultivation of a shared mental model dedicated to data-driven, inclusive inquiry.

# 5 Conclusion

This study illustrates the existing and emerging mental models of teachers' collaboration pre- and post-LS cycles. The mental models described in this study were from the experiences of selected preservice and in-service teachers in mathematics and SPED. First, the initial perceptions of teachers' collaboration were limited to idea sharing and planning activities, but a notable shift toward co-creation and task division emerged after LS experiences. This transition represents more than a simple behavioral adjustment; it constitutes an accommodation of mental schemas (McCarthy et al., 2021) in which educators progress from a self-perception of isolated expertise toward a recognized state of professional interdependence. Second, the existing structure of collaboration was mostly intradisciplinary, with occasional multidisciplinary instances. However, the participants became more open to the transdisciplinary approach to collaboration post-LS implementations. Participating mathematics and SPED teachers cultivated cognitive syncretism (Gregory et al., 2013) in which the maintenance of mathematical integrity and the assurance of student accessibility were merged into a single, cohesive responsibility. Third, LS experiences can be beneficial for both preservice and in-service teachers. For pre-service teachers, it can provide an opportunity to bridge the gap between theoretical knowledge and practical application. For in-service teachers, it can offer a chance to reflect on their teaching practices and identify areas for improvement. LS participation catalyzed reciprocal learning (Wu and Liu, 2024), prompting an equitable exchange where educators shared and integrated their respective disciplinary insights. Finally, the collaborative structure involving math and SPED teachers stimulates positive shifts in the objectives and methods of collaboration, which could lead to a more inclusive approach. Participant concerns regarding readiness, replicability, and sustainability reveal that this collaborative "shift" is an ongoing process of oppositions and negotiations (Capone et al., 2024) rather than a static accomplishment.

The shift in teachers' mental models of collaboration from mere idea sharing and basic planning to co-creation and purposeful task division is fundamentally driven by the systematic structure and core philosophy of LS (Fernandez, 2002b). Initial collaborative efforts (class observations, field studies, teaching internships) are often logistical, focusing on dividing curriculum units to reduce individual workload or exchanging successful activities without deep scrutiny. This is a form of collaboration for efficiency. LS experiences, however, transforms this by introducing shared accountability focused not on the teacher, but on the student. It forces a shift from "what I do" to "how students learn." The process starts with a clearly defined, shared student learning goal, a specific misconception to address, or promote inclusive learning. This shared focus necessitates co-creation—teachers must collectively build a lesson from the ground up to achieve that specific outcome, anticipating student thinking and potential roadblocks (Hiebert et al., 2002; Takahashi and McDougal, 2016). The joint lesson observations and post-lesson conferences then provided objective student data, moving the conversation beyond subjective opinion to evidence-based analysis. This data-driven, iterative critique rapidly builds trust and professional interdependence (Lewis et al., 2004; Vangrieken et al., 2015). Because the entire team jointly owns the lesson's success or failure, tasks are divided to leverage specialized expertise (e.g., one teacher focusing on high-level questioning, another on materials design, and a third on collecting observation data), thus shifting task division from simply lightening the load to actively improving the collective product. In essence, LS provides the structure, focus on student data, and mutual vulnerability needed to elevate teacher interaction from simple surface-level sharing to a rigorous, knowledge-generating process of co-creation.

Implicit mental models may restrict an individual's capacity for change, learning, and career advancement (Darling-Hammond and Richardson, 2009; Senge et al., 2012). Thus, teachers' awareness of their mental models of collaboration and making them visible are fundamental in their teaching practice. This can be achieved by embedding opportunities for preservice and in-service teachers to work together during their teacher preparation and continuing professional development programs. Although preservice SPED teacher courses may incorporate some focus on teacher collaboration (Harvey et al., 2008), overall, teacher preparation programs have largely failed to provide specific training on collaboration (Friend and Cook, 2013). The LS activities used in this research can be included in teacher training programs. This will help both preservice and in-service teachers learn about the complexities of collaboration by working with other professionals. This will also provide an avenue for both preservice and in-service teachers to learn from the new perspectives and practices that may transpire during collaborations. This integration can be achieved by making LS an embedded requirement within field studies and teaching internship experiences, moving beyond general observation toward structured inquiry. Preservice teachers could be required to complete mini cycles where they work in small, fixed teams to design a "research lesson" centered on a specific student learning difficulty or misconception. This process could allow them to view their lesson plan not as a fixed product, but as a testable hypothesis about how students will learn. Furthermore, training must explicitly scaffold the co-creation process by teaching professional norms, assigning equitable roles (e.g., data collector, facilitator), and using structured observation protocols that focus solely on student actions and outcomes. To overcome the natural anxiety of novice teachers, programs should normalize vulnerability through the use of video-recorded micro-teaching sessions for peer analysis and by modeling authentic LS cycles. By aligning coursework with these principles—framing pedagogical content knowledge as the primary output of collective analysis—teacher training can effectively bridge the theory-practice gap and cultivate a cohort of educators who are inherently data-driven and committed to continuous, shared professional growth. Research shows that successful collaboration relies on trust, valuing the expertise of others, and being open to change (Paulsrud and Nilholm, 2023; Skrtic, 1991; Weiss et al., 2017). Hence, this approach can help use collaborative strategies more effectively, especially in promoting inclusive education.

Additionally, the participants' concerns about the readiness, replicability, and sustainability of their collaborative practices call for deeper discussion and reflection. Once explored, these concerns can be valuable to further understand the diverse mental models of teachers' collaboration and may assist in negotiating future collaborations in schools. By examining teachers' mental models of collaboration, education leaders and institutions can develop targeted preparation and professional development programs to promote a more inclusive learning environment. To effectively nurture collaboration, the findings of this study further implied that these innovative preparation and professional development opportunities should involve representatives from diverse disciplines.

## 6 Limitations and future research

While the presented empirical results are promising, it is also equally important to consider the limitations inherent in this study. First, the documented mental models were based on the experiences of a small number of involved teachers from the two study sites. Second, school systems are temporary, and any changes can be attributed to a combination of internal and external factors. Third, as emphasized by previous studies, mental models are usually impermanent and unspoken (Mevorach and Strauss, 2012; Senge et al., 2012). Hence, a dynamic educational landscape necessitates periodic examinations of teachers' and other stakeholders' mental models of collaboration. Lastly, contradictory and resistant mental models can be valuable (Toikka and Tarnanen, 2022) and may indicate a need for deeper reflection and discussion. Thus, further research may explore opportunities to enhance collaboration while emphasizing the importance of embracing diverse perspectives for constructive growth.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by University of the Philippines Los Baños Research Ethics Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

MB: Resources, Funding acquisition, Software, Project administration, Writing – review & editing, Supervision, Formal analysis, Writing – original draft, Data curation, Methodology, Visualization, Conceptualization, Investigation, Validation. JP: Writing – review & editing, Writing – original draft. RB: Writing – original draft, Writing – review & editing.

## Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was supported by the Office of International Linkages, University of the Philippines, Quezon City, Philippines (Grant numbers OILCOOP-2024-11, OILCOOP-2024-12) and the Faculty of Education and Society, Malmö University, Malmö, Sweden.

## Acknowledgments

We gratefully acknowledge the support of the University of the Philippines and Malmö University through the UP Office of International Linkages COOPERATE grant program.

## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References


Abu-Alghayth, K. M. (2024). Understanding teachers' lived experiences of instructional collaboration in inclusive and mainstream settings: A transcendental phenomenological approach. *Int. J. Disabil. Dev. Educ.* 72, 321–338. doi: 10.1080/1034912X.2024.2317484

Basister, M. P., Petersson, J., and Baconguis, R. D. (2025a). Educational innovations for an inclusive learning environment: Insights from the teachers' collaboration through lesson study. *Front. Educ.* 10:1610749. doi: 10.3389/feduc.2025.1610749

Basister, M. P., Petersson, J., and Baconguis, R. D. (2025b). Effects of lesson study on the perceived teaching competencies of mathematics and special education teachers. 15, 1–20. *SAGE Open*. doi: 10.1177_21582440251365692

Baumfield, V., Bethel, A., Boyle, C., Katene, W., Knowler, H., Koutsouris, G., et al. (2022). How lesson study is used in initial teacher education: An international review of literature. *Teach. Dev.* 26, 356–372. doi: 10.1080/13664530.2022.2063937

Berry, R. Q., Ellis, M., and Hughes, S. (2014). Examining a history of failed reforms and recent stories of success: mathematics education and Black learners of mathematics in the United States. *Race Ethnicity Educ.* 17, 540–568. doi: 10.1080/13613324.2013.818534

Bonett, D. G. (2012). Replication-extension studies. *Curr. Dir. Psychol. Sci.* 21, 409–412. doi: 10.1177/0963721412459512

Bruer, J. T. (2005). "Cognitive science: Interdisciplinary and intradisciplinary collaboration," in *Interdisciplinary Collaboration: An Emerging Cognitive Science*, 1st Edn, eds S. J. Derry, C. D. Schunn, and M. A. Gernsbacher (Hove: Psychology Press), doi: 10.4324/9781410613073

Bruggink, M., Goei, S. L., and Koot, H. M. (2013). Characteristics of teacher-identified students with special educational needs in Dutch mainstream primary education. *Educ. Res.* 55, 361–375. doi: 10.1080/00131881.2013.844938

Bush, A., and Grotjohann, N. (2020). Collaboration in teacher education: A cross-sectional study on future teachers' attitudes towards collaboration, their intentions to collaborate and their performance of collaboration. *Teach. Teach. Educ.* 88:102968. doi: 10.1016/j.tate.2019.102968

Capone, R., Adesso, M. G., and Manolino, C. (2024). Culturally crafted Lesson Study to improve teachers' professional development in mathematics: A case study in Italian secondary school. *J. Math. Teacher Educ.* 27, 607–636. doi: 10.1007/s10857-023-09578-3

Carrea, V. I., Jones, H. J., Thomas, C. C., and Morsink, C. V. (2005). *Interactive Teaming: Enhancing Programs for Students with Special Needs*. Hoboken, NJ: Pearson Merrill-Prentice Hall.

Carroll, J. M., and Olson, J. R. (1988). "Mental models in human-computer interaction," in *Handbook of Human-Computer Interaction*, ed. M. Helander (Amsterdam: Elsevier).

Castro, E., Cañadas, M. C., and Molina, M. (2022). Difficulties in semantically congruent translation of verbally and symbolically represented algebraic statements. *Educ. Stud. Math.* 109, 593–609. doi: 10.1007/s10649-021-10088-3

Cheung, W., and Wong, W. (2014). Does lesson study work? : A systematic review on the effects of lesson study and learning study on teachers and students. *Int. J. Lesson Learn. Stud.* 3, 137–149. doi: 10.1108/IJLLS-05-2013-0024

Coenders, F., and Verhoef, N. (2019). Lesson study: professional development (PD) for beginning and experienced teachers. *Professional Dev. Educ.* 45, 217–230. doi: 10.1080/19415257.2018.1430050

Daneshpour, H., and Kwegyir-Afful, E. (2022). Analysing transdisciplinary education: A scoping review. *Sci. Educ.* 31, 1047–1074. doi: 10.1007/s11191-021-00277-0

Darling-Hammond, L., and Richardson, N. (2009). Teacher learning: What matters? *Educ. Leadersh.* 66, 46–53.

DeCuir-Gunby, J., Marshall, P., and Mcculloch, A. (2011). Developing and using a codebook for the analysis of interview data: An example from a professional development research project. *Field Methods* 23, 136–155. doi: 10.1177/1525822X10388468

Dudley, P., Xu, H., Vermunt, J. D., and Lang, J. (2019). Empirical evidence of the impact of lesson study on students' achievement, teachers' professional learning and on institutional and system evolution. *Eur. J. Educ.* 54, 202–217. doi: 10.1111/ejed.12337

Fernandez, C. (2002a). Learning from Japanese approaches to professional development. *J. Teach. Educ.* 53, 393–405. doi: 10.1177/002248702237394

Fernandez, M. (2002b). Lesson study: A case in which research informed the practice of professional development. *Asia Pac. J. Teach. Educ.* 30, 163–174.

FEU Public Policy Center. (2017). *CHED Memorandum Order No. 75, 2017: Policies, Standards, and Guidelines for Bachelor of Secondary Education (BSEd)*. Philippines: FEU Public Policy Center.

Friend, M., and Cook, L. (2013). *Interactions: Collaboration Skills for School Professionals*. Upper Saddle River: Pearson.

Gándara, P., and Mordechay, K. (2017). Demographic change and the new (and not so new) challenges for Latino education. *Educ. Forum.* 81, 148–159. doi: 10.1080/00131725.2017.1280755

García-Martínez, I., Montenegro-Rueda, M., Molina-Fernández, E., and Fernández-Batanero, J. M. (2021). Mapping teacher collaboration for school success. *School Effect. School Improvement* 32, 631–649. doi: 10.1080/09243453.2021.1925700

Gasparrini, A. (2021). The case time series design. *Epidemiology* 32, 829–837. doi: 10.1097/EDE.0000000000001410

Ghedin, E. (2021). "Social innovation through collaboration for enabling educational inclusive EcoSystems: Following Italy's lead," in *Instructional Collaboration in International Inclusive Education Contexts (International Perspectives on Inclusive Education)*, Vol. 17, eds S. R. Semon, D. Lane, and P. Jones (Bingley: Emerald Publishing Limited), 71–96. doi: 10.1108/S1479-363620210000017008

Gräsel, C., Fußangel, K., and Pröbstel, C. (2006). Lehrkräfte zur Kooperation anregen-eine Aufgabe für Sisyphos? [Encouraging teachers to cooperate – a Sisyphean task?]. *Zeitschrift für Pädagogik* 52, 205–219. German.

Greene, D., and David, J. L. (1983). A research design for generalizing from multiple case studies. *Eval. Program Plann.* 7, 73–85. doi: 10.1016/0149-7189(84)90027-2

Gregory, E., Lytra, V., Choudhury, H., Ilankuberan, A., Kwapong, A., and Woodham, M. (2013). Syncretism as a creative act of mind: The narratives of children from four faith communities in London. *J. Early Childh. Literacy.* 13, 322–347. doi: 10.1177/1468798412453151

Gutiérrez, R. (2013). The sociopolitical turn in mathematics education. *J. Res. Math. Educ.* 44, 37–68. doi: 10.5951/jresematheduc.44.1.0037

Haim, O., Strauss, S., and Ravid, D. (2004). Relations between EFL teachers' formal knowledge of grammar and their in-action mental models of children's minds and learning. *Teach. Teach. Educ.* 20, 861–880.

Halkias, D., Neubert, M., Thurman, P. W., and Harkiolakis, N. (2022). *The Multiple Case Study Design: Methodology and Application for Management Education*, 1st Edn. Milton Park: Routledge, doi: 10.4324/9781003244936

Hargreaves, A. (1994). *Changing Teachers, Changing Times. Teachers' Work and Culture in Post-Modern Times*. London: Redwood Books.

Harvey, M. W., Yssel, N., Bauserman, A. D., and Merbler, J. B. (2008). Preservice teacher preparation for inclusion. *Remedial Special Educ.* 31, 24–33. doi: 10.1177/0741932508324397

Heldens, H., Bakx, A., and den Brok, P. (2015). Teacher educators' collaboration in subject departments: Collaborative activities and social relations. *Educ. Res. Eval.* 21, 515–536. doi: 10.1080/13803611.2016.1153488

Hernandez, S. (2013). Collaboration in special education: Its history, evolution, and critical factors necessary for successful implementation. *US China Educ. Rev.* 3, 480–498.

Hiebert, J., Gallimore, R., and Stigler, J. W. (2002). A knowledge base for the teaching profession: Can the U.S. learn from others? *Educ. Res.* 31, 3–12. doi: 10.3102/0013189X031005003

Hsieh, H. F., and Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qual. Health Res.* 15, 1277–1288. doi: 10.1177/1049732305276687

Jones, N. A., Ross, H., Lynam, T., Perez, P., and Leitch, A. (2011). Mental models: an interdisciplinary synthesis of theory and methods. *Ecol. Soc.* 16:46.

Joseph, N. M., Hailu, M., and Boston, D. (2017). Black women's and girls' persistence in the P–20 mathematics pipeline: two decades of children, youth, and adult education research. *Rev. Res. Educ.* 41, 203–227. doi: 10.3102/0091732X16689045

Kager, K., Kalinowski, E., Jurczok, A., and Vock, M. (2024). A systematic review of transparency in lesson study research: How do we report on the observation and reflection stages? *Front. Educ.* 9:1322624. doi: 10.3389/feduc.2024.1322624

Kalyva, E. (2013). *Collaboration Between Parents of Children with Autism Spectrum Disorders and Mental Health Professionals*. London: InTech, doi: 10.5772/53966

Kang, H. (2021). Sample size determination and power analysis using the G*Power software. *J. Educ. Eval. Health Prof.* 18, 1–12. doi: 10.3352/jeehp.2021.18.17

Klein, J. T. (2018). "Learning in transdisciplinary collaborations: A conceptual vocabulary," in *Transdisciplinary Theory, Practice and Education*, eds D. Fam, L. Neuhauser, and P. Gibbs (Cham: Springer), doi: 10.1007/978-3-319-93743-4_2

Kotilainen, N., Sirkko, R., and Takala, M. (2025). Collaboration between subject teachers and special education teachers in Finnish lower secondary schools. *Educ. Inquiry* 1–16. doi: 10.1080/20004508.2025.2518776

Krippendorff, K. (2019). *Content Analysis*. Thousand Oaks, CA: SAGE Publications, Inc, doi: 10.4135/9781071878781

Larnell, G. V. (2016). More than just skill: Examining mathematics identities, racialized narratives, and remediation among black Undergraduates. *J. Res. Math. Educ. JRME* 47, 233–269. doi: 10.5951/jresematheduc.47.3.0233

Leatherman, J. (2009). Teachers' voices concerning collaborative teams within an inclusive elementary school. *Teach. Educ.* 20, 189–202. doi: 10.1080/10476210902718104

Lehman, B. A. (2012). *Promoting Learning by Inducing and Scaffolding Cognitive Disequilibrium and Confusion Through System Feedback*. Electronic Theses and Dissertations, Vol. 414. Memphis: University of Memphis Digital Commons.

Lewis, C. (2002). *Lesson Study: A Handbook of Teacher-Led Instructional Change*. Philadelphia, PA: Research for Better Schools, Inc.

Lewis, C., Perry, R., and Hurd, J. (2004). A tool for building essential capacities in education: Japanese lesson study. *N. Engl. J. Public Policy* 20, 147–161.

Ma, C., Park, S. H., and Shang, J. (2018). Inter-and intra-disciplinary collaboration and patient safety outcomes in US acute care hospital units: A cross-sectional study. *Int. J. Nurs. Stud.* 85, 1–6. doi: 10.1016/j.ijnurstu.2018.05.001

Martin, D. B. (2019). Equity, inclusion, and antiblackness in mathematics education. *Race Ethnicity Educ.* 22, 459–478. doi: 10.1080/13613324.2019.1592833

Martin, D. B., Anderson, C. R., and Shah, N. (2017). "Race and mathematics education," in *Compendium for Research in Mathematics Education*, ed. J. Cai (Reston, VA: National Council of Teachers of Mathematics), 607–636.

Masters, C., O'Toole Baker, V., and Jodon, H. (2013). Multidisciplinary, team-based learning: The simulated interdisciplinary to multidisciplinary progressive-level education (SIMPLE©) approach. *Clin. Simul. Nurs.* 9, e171–e178. doi: 10.1016/j.ecns.2011.11.007

Mathieu, J. E., Goodwin, G. F., Heffner, T. S., Salas, E., and Cannon-Bowers, J. A. (2000). The influence of shared mental models on team process and performance. *J. Appl. Psychol.* 85, 273–283. doi: 10.1037/0021-9010.85.2.273

McCarthy, S., O'Raghallaigh, P., Fitzgerald, C., and Adam, F. (2021). Shared and fragmented understandings in interorganizational IT project teams: An interpretive case study. *Int. J. Project Manag.* 39, 762–773. doi: 10.1016/j.ijproman.2021.07.003

Mejía-Rodríguez, A. M., and Kyriakides, L. (2022). What matters for student learning outcomes? A systematic review of studies exploring system-level factors of educational effectiveness. *Rev. Educ.* 34:e3374. doi: 10.1002/rev3.3374

Mevorach, M., and Strauss, S. (2012). Teacher educators' in-action mental models in different teaching situations. *Teach. Teach. Theory Pract.* 18, 25–41. doi: 10.1080/13540602.2011.622551

Miller-Young, J., and Yeo, J. (2015). Conceptualizing and communicating SoTL: A framework for the field. *Teach. Learn. Inquiry* 3, 37–53. doi: 10.20343/teachlearninqu.3.2.37

Moseley, C., Desjean-Perrotta, B., and Utley, J. (2010). The draw-an-environment test rubric (DAET-R): Exploring pre-service teachers' mental models of the environment. *Environ. Educ. Res.* 16, 189–208. doi: 10.1080/13504620903548674

Mutodi, P., and Mogege, M. (2021). Learning mathematical symbolization: Conceptual challenges and instructional strategies in secondary schools. *Bolema Boletim de Educação Mat.* 35, 1180–1199. doi: 10.1590/1980-4415v35n70a29

Ní Bhroin, Ó, and King, F. (2019). Teacher education for inclusive education: A framework for developing collaboration for the inclusion of students with support plans. *Eur. J. Teach. Educ.* 43, 38–63. doi: 10.1080/02619768.2019.1691993

Norman, D. A. (1983). "Some observations on mental models," in *Mental Models*, eds D. Gentner and A. L. Stevens (Hillsdale, NJ: Erlbaum), 7–14.

North, C., Clelland, T., and Lindsay, H. (2018). Phases in collaboration: Using Schwab's deliberation to respond to change in teacher education. *Studying Teach. Educ.* 14, 212–230. doi: 10.1080/17425964.2018.1450239

Patton, M. Q. (2015). *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*, 4th Edn. Thousand Oaks, CA: Sage Publications.

Paulsrud, D., and Nilholm, C. (2023). Teaching for inclusion – a review of research on the cooperation between regular teachers and special educators in the work with students in need of special support. *Int. J. Inclusive Educ.* 27, 541–555. doi: 10.1080/13603116.2020.1846799

Pellegrino, A., Weiss, M., and Regan, K. (2015). Learning to collaborate: General and special educators in teacher education. *Teach. Educ.* 50, 187–202. doi: 10.1080/08878730.2015.1038494

Perera-Rodríguez, V. H., and Moriña Díez, A. (2017). Technological challenges and students with disabilities in higher education. *Exceptionality* 27, 65–76. doi: 10.1080/09362835.2017.1409117

Peter, F. (2013). Principles of good practice in SoTL. *Teach. Learn. Inquiry ISSOTL J.* 1, 121–125. doi: 10.20343/teachlearninqu.1.1.121

Pimmer, C., Pachler, N., and Nierle, J. (2012). Learning through inter- and intradisciplinary problem solving: Using cognitive apprenticeship to analyse doctor-to-doctor consultation. *Adv. Health Sci. Educ.* 17, 759–778. doi: 10.1007/s10459-012-9350-7

Pozas, M., and Letzel-Alt, V. (2023). Teacher collaboration, inclusive education and differentiated instruction: A matter of exchange, co-construction, or synchronization? *Cogent Educ.* 10:2240941. doi: 10.1080/2331186X.2023.2240941

Rahimi, S., and Khatooni, M. (2024). Saturation in qualitative research: An evolutionary concept analysis. *Int. J. Nurs. Stud. Adv*. 6:100174. doi: 10.1016/j.ijnsa.2024.100174

Rainforth, B., and England, J. (1997). Collaboration for inclusion. *Educ. Treatment Children* 20:85.

Republic of the Philippines Department of Education. (2016). The Learning Action Cell as K to 12 Basic Education Program School-Based Continuing Professional Development Strategy for the Improvement of Teaching and Learning. Available online at: https://www.deped.gov.ph/wp-content/uploads/2016/06/DO_s2016_035.pdf (accessed September 15, 2025).

Republic of the Philippines Department of Education. (2023). Multi-Year Guidelines on the Results-Based Performance Management System-Philippine Professional Standards for Teachers. Available online at: https://www.deped.gov.ph/wp-content/uploads/DM_s2023_008.pdf (accessed September 15, 2025).

Rouse, W. B., and Morris, N. M. (1986). On looking into the black box: Prospects and limits in the search for mental models. *Psychol. Bull.* 100, 349–363. doi: 10.1037/00332909.100.3.349

Rubenstein, R. N., and Thompson, D. R. (2001). Discuss with your colleagues: Learning mathematical symbolism: Challenges and instructional strategies. *Math. Teach.* 94, 265–271. doi: 10.5951/MT.94.4.0265

Scherer, P. (2019). "Professionalization for inclusive mathematics education: Challenges for subject-specific teacher education," in *Inclusive Mathematics Education*, eds D. Kollosche, R. Marcone, M. Knigge, M. G. Penteado, and O. Skovsmose (Cham: Springer), doi: 10.1007/978-3-030-11518-0_35

Schoenfeld, A. H. (2004). The math wars. *Educ. Policy* 18, 253–286. doi: 10.1177/0895904803260042

Senge, P., Lucas, T., Smith, B., Dutton, J., Kleiner, A., and Cambron-McCabe, N. (2012). *Schools that Learn: A Fifth Discipline Fieldbook for Educators, Parents, and Everyone Who Cares about Education*. Boston, MA: Nicholas Brealey Publishing.

Shah, N. (2017). Race, ideology, and academic ability: A relational analysis of racial narratives in mathematics. *Teach. Coll. Rec. Voice Scholarsh. Educ.* 119, 1–42. doi: 10.1177/016146811711900705

Skrtic, T. (1991). *Behind Special Education*. Denver: Love.

Snell, M. E., and Janney, R. (2005). *Collaborative Teaming*, 2nd Edn. Baltimore: Paul H. Brookes Publishing Co.

Stake, R. E. (2010). *Qualitative Research: Studying How Things Work*. New York, NY: Guilford Press.

Stein, M. K., Grover, B. W., and Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *Am. Educ. Res. J.* 33, 455–488. doi: 10.3102/00028312033002455

Stephanie, L. M. (2010). Implications of collaboration in education. *Acad. Leadersh. Online J.* 8:35. doi: 10.58809/OULX4484

Stigler, J. W., and Hiebert, J. (1999). *The Teaching Gap: Best Ideas from the World's Teachers for Improving Education in the Classroom*. New York: Free Press.

Stinson, D. W., Bullock, E. C. (2012). Critical postmodern theory in mathematics education research: a praxis of uncertainty. *Educ. Stud. Math.* 80, 41–55. doi: 10.1007/s10649-012-9386-x

Strachan, S., Logan, L., Willison, D., Bain, R., Roberts, J., Mitchell, I., et al. (2023). Reflections on developing a collaborative multi-disciplinary approach to embedding education for sustainable development into higher education curricula. *Emerald Open Res.* 1:9. doi: 10.1108/EOR-09-2023-0007

Takahashi, A., and McDougal, T. (2016). Collaborative lesson planning: A tool for maximizing the power of lesson study. *ZDM Math. Educ.* 48, 511–526.

Tan, S., Goei, S. L., and Willemse, T. M. (2024). Global insights on lesson study in initial teacher education: A systematic literature review encompassing English, Japanese, and Chinese language sources. *Teach. Teach. Educ.* 152:104791. doi: 10.1016/j.tate.2024.104791

Tarnanen, M., Kostiainen, E., Kaukonen, V., Martin, A., and Toikka, T. (2021). Towards a learning community: Understanding teachers' mental models to support their professional development and learning. *Professional Dev. Educ.* 50, 1019–1033. doi: 10.1080/19415257.2021.1959383

Ten Braak, D., Lenes, R., Purpura, D. J., Schmitt, S. A., and Størksen, I. (2022). Why do early mathematics skills predict later mathematics and reading achievement? The role of executive function. *J. Exp. Child Psychol.* 214:105306. doi: 10.1016/j.jecp.2021.105306

Toikka, T., and Tarnanen, M. (2022). Understanding teachers' mental models of collaboration to enhance the learning community. *Educ. Stud.* 50, 1114–1131. doi: 10.1080/03055698.2022.2052809

Tomlinson, C., Brighton, C., Hertberg, H., Callahan, C., Moon, T., Brimijoin, K., et al. (2003). Differentiating instruction in response to student readiness, interest, and learning profile in academically diverse classrooms: A review of the literature. *J. Educ. Gifted* 27, 119–145. doi: 10.1177/016235320302700203

Utley, B., and Rapport, M. (2002). Essential elements of effective teamwork: Shared understanding and differences between special educators and related service providers. *Phys. Disabil. Educ. Relat. Serv.* 20, 9–47.

Vangrieken, K., Dochy, F., Raes, E., and Kyndt, E. (2015). Teacher collaboration: A systematic review. *Educ. Res. Rev.* 15, 17–40. doi: 10.1016/j.edurev.2015.04.002

Verhoef, N., Tall, D., Coenders, F., and Smaalem, D. V. (2014). The complexities of a lesson study in a Dutch situation: mathematics teacher learning. *Int. J. Sci. Math. Educ.* 12, 859–881. doi: 10.1007/s10763-013-9436-6

Verschaffel, L., Greer, B., and De Corte, E. (2010). "Mathematics learning," in *International Encyclopedia of Education*, 3rd Edn, Vol. 5, eds P. Peterson, E. Baker, and B. McGaw (Amsterdam: Elsevier), 401–406.

Videla, R., Parada, F. J., Aros, M. B., Ramírez, P., Sarzosa, A., Jorquera, D., et al. (2025). Breaking barriers in education: Leveraging 3E approach and technology to foster inclusion for SEN students. *Front. Educ.* 10:1554314. doi: 10.3389/feduc.2025.1554314

Weiss, M. P., Pellegrino, A., and Brigham, F. J. (2017). Practicing collaboration in teacher preparation: Effects of learning by doing together. *Teach. Educ. Spec. Educ.* 40, 65–76. doi: 10.1177/0888406416655457

Welch, M. (1998). Collaboration: staying on the bandwagon. *J. Teach. Educ.* 49, 26–37. doi: 10.1177/0022487198049001004

Welch, M., and Tulbert, B. (2000). Practitioners' perspectives of collaboration: A social validation and factor analysis. *J. Educ. Psychol. Consult.* 11, 357–378. doi: 10.1207/S1532768XJEPC113\&4_05

Wu, N., and Liu, Y. (2024). "Professional development of Chinese university-based teacher educators working as guide professors in the reciprocal learning program," in *West-East Reciprocal Learning in Teacher Education. Intercultural Reciprocal Learning in Chinese and Western Education*, eds S. Xu, Y. Liu, Z. Zhang, M. Connelly, and C. Chi (Cham: Palgrave Macmillan), doi: 10.1007/978-3-031-69714-2_10

Ysseldyke, J. (2005). Assessment and decision making for students with learning disabilities: What if this is as good as it gets? *Learn. Disabil. Quart*. 28:125. doi: 10.2307/1593610

Zavala, M. D. (2014). Latina/o youth's perspectives on race, language, and learning mathematics. *J. Urban Math. Educ.* 7, 55–87.

Zhang, X., and Zhang, Y. (2025). Exploring the collective agency of postgraduate students in an academic study group: A social network perspective. *Learn. Cult. Soc. Interaction* 52:100908. doi: 10.1016/j.lcsi.2025.100908