



Transformative learning: noticing student strengths through frame shifting

Thorsten Scheiner^{1,2}

Accepted: 29 June 2025 / Published online: 7 July 2025
© The Author(s) 2025

Abstract

This exploratory study investigates the dynamics of frame shifting in teacher noticing, examining how structured pedagogical interventions support the development of strength-based noticing practices. The research offers theoretical insights by exploring mechanisms of professional transformation through an integrated framework synthesising professional noticing, transformative learning theory, and frame analysis. During an intensive two-week teacher education course, twenty-six prospective secondary mathematics teachers engaged with a structured coding scheme designed as both an analytical tool and pedagogical scaffold. Analysis of written responses to a standardised noticing task revealed decreases in deficit-based orientations and increases in strength-based orientations. These findings suggest that structured frame shifting—the deliberate practice of changing interpretive frameworks—supports teachers in developing more sophisticated ways of recognising and building upon student thinking. This study contributes evidence for mechanisms through which teachers develop new ways of attending, interpreting, and responding to students’ mathematical thinking, with implications for designing teacher education programs that promote equity-oriented teaching practices.

Keywords Teacher noticing · Transformative learning · Frame shifting · Strength-based approaches · Mathematics teacher education · Equity in mathematics education

1 Introduction

When teachers focus on the substance of students’ mathematical thinking, more opportunities for student learning emerge (Fennema et al., 1996). Over the past two decades, research on teacher noticing has gained traction in educational research (see König et al., 2022 for a review), as it centres teachers’ attention on students’ thinking and positively influences their learning (Schoenfeld, 2011). Professional noticing involves teachers attending to and making sense of students’ mathematical ideas (Sherin et al., 2011).

An underexamined dimension of professional noticing concerns how teachers’ interpretive frames—the schemas through which teachers perceive and make sense of classroom events—shape what they attend to and how they interpret and respond to student thinking (Sherin & Russ, 2014).

Of particular significance are the orientations these frames can take, specifically deficit-based orientations that focus on student limitations and strength-based orientations that emphasise student capabilities. This distinction is crucial given evidence that frames with deficit-based orientations constrain learning opportunities and harm students’ mathematical identities, especially for marginalised students (Adiredja & Louie, 2020).

The conceptualisation of professional noticing has evolved from a cognitive skill to a complex social practice shaped by teachers’ interpretive frames (Louie et al., 2021; Scheiner, 2021). When teachers operate from deficit-based frames that focus on student limitations, they may overlook valuable mathematical thinking and inadvertently restrict students’ opportunities to develop robust mathematical understandings (Louie, 2017). In contrast, strength-based frames highlight and build upon students’ capabilities, fostering equitable and empowering learning environments (Crespo, 2000; Jilk, 2016; Kalinec-Craig et al., 2021; Othmann et al., 2025; Scheiner, 2023).

This raises critical questions about how teacher education programs can systematically support prospective teach-

✉ T. Scheiner
thorsten.scheiner@fu-berlin.de

¹ Freie Universität Berlin, Berlin, Germany

² Institute for Learning Sciences and Teacher Education, Australian Catholic University, Brisbane, Australia

ers in developing strength-based noticing practices. While research has explored various approaches to developing teacher noticing skills (see Amador et al., 2021; Santagata et al., 2021; Weyers et al., 2023), significant gaps remain in understanding: (a) how frames influence noticing practices; (b) the mechanisms through which teachers shift from deficit-based to strength-based frames; and (c) what specific processes support transformative learning in noticing.

This study addresses these gaps by examining structured opportunities for frame shifting in teacher education and their potential role in supporting prospective teachers' development of strength-based practices. Frame shifting—the conscious practice of changing interpretive frameworks—was integrated into the course design through explicit tools and guided reflection activities. The following questions guide this research:

What patterns emerge in prospective teachers' noticing practices when engaging with structured frame shifting activities, and what processes appear to support any observed changes from deficit-based to strength-based orientations?

This study contributes to the field in several ways. Theoretically, it explores an integrated framework synthesising professional noticing, transformative learning theory, and frame analysis to illuminate mechanisms of professional transformation. Methodologically, it introduces a structured coding scheme that functions as both an analytical tool and a transformative learning scaffold. Practically, it offers preliminary design principles for teacher education programs seeking to develop strength-based noticing practices through structured frame shifting.

2 Theoretical background

Three research domains appear critical for understanding the development of strength-based noticing practices: professional noticing in mathematics education, strength-based approaches in mathematics education, and transformative learning through frame shifting. These domains form an integrated theoretical framework where transformative learning theory mediates the relationship between professional noticing and strength-based approaches.

2.1 Teacher noticing in mathematics education

Professional noticing has become central in mathematics education as a framework for understanding how teachers see and make sense of classroom interactions (see Weyers et al., 2024 for a review). Contemporary research integrates cognitive, sociocultural, and equity perspectives to deepen the understanding of this complex practice.

The cognitive perspective views noticing as interconnected mental skills for processing classroom events (Sherin et al., 2011). These skills encompass three core practices: attending to critical aspects of student reasoning, interpreting student thinking, and deciding how to respond through targeted instructional actions (Jacobs et al., 2010). Attending involves focusing on mathematically significant features within classroom complexity (van Es & Sherin, 2002). Interpreting requires sense-making of students' mathematical ideas, attributing meaning, value, or significance to their thinking (Scheiner & Montes, 2024). Deciding how to respond involves planning instructional moves aligned with student thinking (Jacobs & Empson, 2016) to effectively support learning (Stockero et al., 2022).

Recent research highlights noticing as a value-laden practice shaped by teachers' goals, resources, and orientations (Schoenfeld, 2011). The sociocultural perspective emphasises professional noticing—or professional vision (Goodwin, 1994)—as cultural practices of coding (categorising observations via professional frameworks), highlighting (marking what is deemed noteworthy in complex situations), and creating representations (creating artefacts that capture and communicate professional ways of seeing) (see Louie, 2018). Professional learning communities help develop shared ways of seeing and making sense of classroom interactions through collaborative discussions (Sherin & van Es, 2009).

Equity-focused research shows how noticing practices can perpetuate or disrupt educational inequities (Hand, 2012; Shah & Coles, 2020; van Es et al., 2022). Implicit bias, cultural assumptions, and institutional contexts shape noticing, often privileging certain forms of mathematical thinking while marginalising others (Jilk, 2016; Louie et al., 2021; Mendez & van Es, 2024).

A significant development in this field has been research on learning to notice—the process by which teachers develop awareness of, and consciously cultivate, more effective ways of their own noticing practices (Mason, 2002, 2011). Mason emphasised the importance of recognising not just what one notices, but how and why, both in the moment and in reflection. This metacognitive awareness enables teachers to examine and refine their professional noticing (e.g., Patterson Williams et al., 2020; Rubin & van Es, 2023). Such work highlights that learning to notice involves not only directing attention but also becoming aware of the interpretive lenses that shape that attention. The present study builds on these insights by examining how structured frame shifting can support the development of such awareness, particularly in relation to recognising students' mathematical strengths.

2.2 From deficit-based to strength-based approaches in mathematics education

Deficit-based perspectives have historically dominated mathematics education (Aguirre et al., 2013; Gutiérrez, 2013; Louie, 2017), framing students' mathematical understanding primarily through perceived gaps, misconceptions, and deviations from normative expectations. In classroom practice, these perspectives manifest through evaluating student work against standardised benchmarks, focusing instructional attention on correcting errors, and positioning students as lacking necessary knowledge.

Research demonstrates that these deficit-based perspectives can significantly constrain learning opportunities and harm students' mathematical identities (Aguirre et al., 2013). Deficit frames disproportionately affect students from marginalised communities, whose mathematical thinking may be overlooked or devalued when it differs from dominant norms (Adiredja & Louie, 2020).

Importantly, deficit-based approaches are not simply characterised by attending to errors or misconceptions, which can be valuable observations for supporting learning. Rather, deficit-based approaches are distinguished by two key features: first, they focus predominantly on shortcomings with little recognition of existing understandings and strengths; second, they attribute these shortcomings to deficiencies within students themselves, disconnected from educational contexts and opportunities to learn (Adiredja & Louie, 2020).

Strength-based approaches challenge deficit narratives by actively positioning students as capable mathematical thinkers with existing resources for learning. In practice, these perspectives manifest through recognising and building upon students' current understanding, viewing diverse solution strategies as evidence of mathematical thinking, and treating errors as windows into student reasoning rather than deficiencies (Boaler, 2022).

Crucially, strength-based approaches do not ignore errors or misunderstandings but reframe how these are interpreted and addressed. Whereas deficit-based approaches might view an error as evidence of a student's inability to understand a concept, strength-based approaches might view the same error as a reasonable consequence of the student's current understanding, revealing productive pathways for instruction. The distinction lies in how the error is *framed*—as evidence of deficiency or as a meaningful aspect of developing mathematical thinking.

2.3 Transformative learning through frame shifting

Transformative learning theory offers a foundation for understanding how individuals change their interpretive frames through critical reflection and discourse (Mezirow, 2000).

Mezirow's theory centres on how individuals transform their meaning perspectives—the frameworks of assumptions and expectations through which we filter experiences. This transformation involves challenging existing assumptions, engaging in critical reflection, exploring and testing new perspectives, building competence in these new perspectives, and integrating these changes into one's identity and practice.

This study draws on frame analysis to examine how teachers develop new ways of noticing student thinking. Frames, as conceptualised by Goffman (1974), are interpretive schemas that organise experience and guide action. In educational contexts, a teacher's frame determines what aspects of student work they attend to, how they interpret student thinking, and what instructional responses they consider appropriate (Russ & Luna, 2013; Sherin & Russ, 2014). Frame shifting—the deliberate practice of changing one's interpretive framework—offers a promising mechanism for transformative learning in noticing.

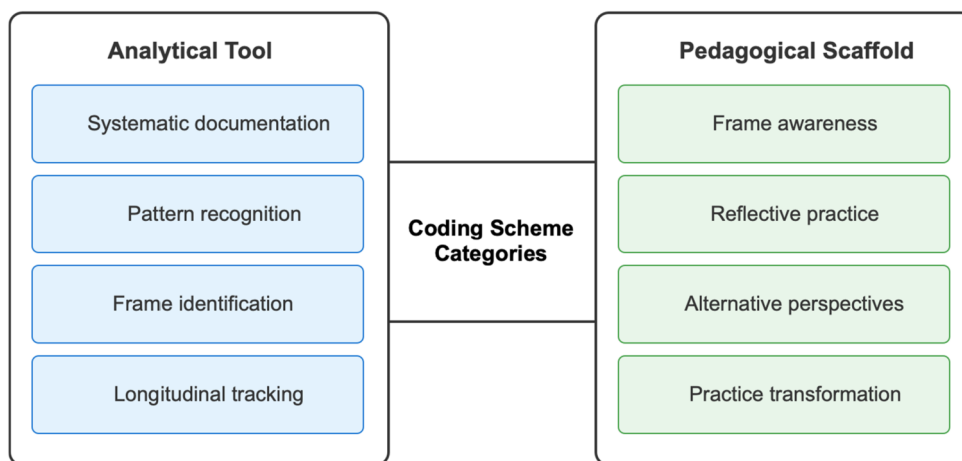
Frame shifting aligns with transformative learning theory by providing structured opportunities for critical examination of assumed perspectives and the conscious adoption of alternative frames. This process involves four key elements: First, teachers need to critically reflect on how their frames shape what they notice and value in students' mathematical thinking, often uncovering biases in seemingly neutral observations. Second, they need opportunities for professional dialogue and structured analysis to practice viewing student work through alternative frames. Third, teachers must develop new understandings and actions that fundamentally restructure their perceptions of student mathematical activity. Finally, sustained engagement with alternative perspectives helps embed new ways of seeing into professional practice through ongoing application and refinement.

Recent advances in framing theory further illuminate the complexity of this process. Walsh and Schunn (2025) reconceptualise framing for adaptive teaching expertise, distinguishing between strategic framing (deliberate selection of interpretive frameworks for specific pedagogical purposes) and expansive framing (broadening interpretive repertoires to accommodate diverse student thinking). This distinction aligns with our conceptualisation of frame shifting as both a conscious practice and a developmental process that expands teachers' interpretive capabilities.

3 Theoretical framework

This study advances an integrated framework that bridges professional noticing, transformative learning, and frame analysis to explore how teachers develop strength-based noticing practices. This framework posits that transformative learning may mediate the evolution from deficit-

Fig. 1 The coding scheme's dual function as an analytical tool and pedagogical scaffold. *Note.* The left column delineates the coding scheme's function as an analytical tool for systematic examination, whereas the right column articulates its pedagogical function in scaffolding transformative professional development. The coding scheme categories constitute a theoretical bridge, mediating the interplay between these functions



based to strength-based noticing practices through deliberate frame shifting processes.

The framework is built on three premises: First, teacher noticing is fundamentally shaped by interpretive frames that influence what teachers attend to, how they interpret student thinking, and what instructional moves they consider appropriate. Second, professional noticing provides the structural components through which these frames manifest in practice, whereas strength-based approaches offer alternative frames that emphasise students' capabilities and mathematical potential. Third, transformative learning provides mechanisms for frame shifting through critical reflection and conscious reorientation of perspective.

3.1 The coding scheme as a theoretical tool

Central to this integrated framework is a structured coding scheme (Scheiner, 2023) that operationalises three frame orientations in teacher noticing: deficit-based (focusing on errors, gaps, and limitations), strength-based (highlighting capabilities, potential, and assets), and uncommitted (neither explicitly deficit-based nor strength-based).¹ The scheme serves dual purposes: first as an analytical tool for systematically tracking changes in teacher noticing, and second as a pedagogical scaffold for facilitating transformative learning (see Fig. 1).

3.2 Key theoretical propositions

The theoretical integration manifests in three key propositions:

¹These category terms were first used by Kalinec-Craig et al. (2021), albeit operationalised and applied differently. Here, we use Kalinec-Craig et al.'s (2021) term 'uncommitted' to describe noticing statements that are not explicitly aligned with deficit- or strength-based orientations, and distinguish this from neutral to emphasise that all statements in teaching are value-laden (p. 386).

First, teacher noticing appears to be inherently guided by interpretive frames that shape attention, interpretation, and response (Louie et al., 2021; Russ & Luna, 2013). These frames determine whether attention is directed towards errors and gaps or mathematical potential, whether interpretations evaluate student work against normative standards or seek to understand thinking on its own terms, and whether responses focus on correction or building upon student ideas (Scheiner, 2023). The coding scheme makes these frame orientations explicit, providing a structured way to examine patterns in noticing practices.

Second, frame shifting represents a transformative learning process involving both cognitive and dispositional changes. Teachers need to develop awareness of their current frames, recognise how different frames influence their interpretations of student thinking, practice consciously shifting between frames, and integrate new frames into their professional practice. The coding scheme plays a crucial role in supporting this process by providing concrete examples of deficit-based, strength-based, and uncommitted orientations and by creating pathways for reframing perspectives.

Third, this process of frame shifting occurs through mechanisms such as frame awareness, which involves analysing noticing practices to uncover default orientations, and conscious reframing, where teachers actively practice viewing students' work through different frames to explore how these influence their interpretations and responses. Over time, progressive integration enables teachers to embed strength-based frames into their practice, fostering new habits of noticing and supporting sustained transformations in their professional perspectives.

Figure 2 illustrates how these three theoretical foundations inform this study. Professional noticing provides the structural components (attending, interpreting, and deciding how to respond) situated at the centre. These practices are embedded within interpretive frames that shape how teachers notice student thinking. The outer circle represents the

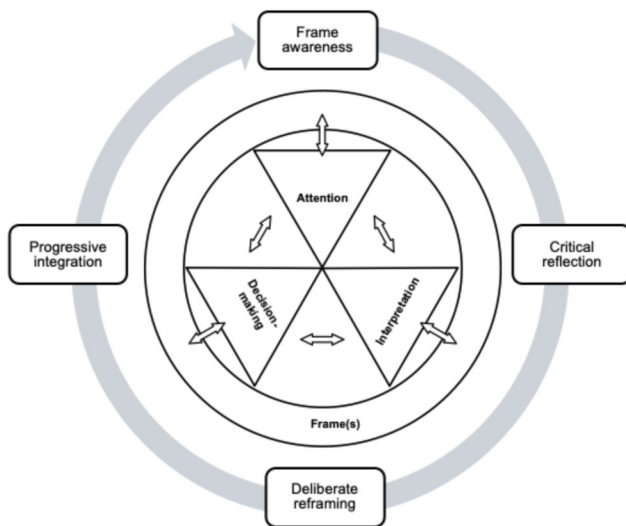


Fig. 2 Integrated theoretical model for transformative learning to noticing. *Note.* The model illustrates the relationships among professional noticing practices (centre), interpretive frames (middle ring), and transformative learning processes (outer ring)

transformative learning processes that facilitate frame shifting through frame awareness, critical reflection, deliberate reframing, and progressive integration.

4 Methods

This study examined how prospective mathematics teachers' noticing practices evolved during an intensive professional learning course on strength-based approaches to mathematics education. A qualitative research design was used, complemented by quantitative analysis of participants' written responses to a standardised noticing task.

4.1 Research design and context

This study employed a methodologically-grounded insider-researcher design, with the author positioned as both course instructor and researcher. This approach facilitated nuanced insights into pedagogical mechanisms (Cochran-Smith & Lytle, 2009) while addressing potential biases through systematic methodological safeguards (blind coding procedures, independent analysis, and data triangulation). The dual positionality enabled deeper understanding of transformative learning processes while maintaining rigorous analytical distance through structured protocols.

The study was designed as research from inception, with data collection integrated into a mathematics education course at a large public university in Germany. The course formed part of a two-year master's teacher education program and was delivered over 34 hours of face-to-face meetings across two weeks. This intensive format minimised

competing coursework distractions and fostered a collaborative professional community essential for transformative learning.

The course followed a theoretically grounded three-phase transformative learning process (Mezirow, 2000). In the initial phase, participants individually analysed student work samples on secondary mathematics topics (fractions, probability, limits) and responded to standardised prompts (Jacobs et al., 2010) to document their attending, interpreting, and instructional decision-making practices. These prompts revealed participants' default frames toward student thinking.

The collaborative analysis phase engaged participants through specific protocols: small groups of 2–3 participants applied the coding scheme (Scheiner, 2023) via structured worksheets that guided their analysis of frame orientations. Following Goodwin's (1994) professional practices, participants engaged in: coding their responses using the coding scheme categories, highlighting instances of different orientations, and creating visual representations of their frames. This structured scaffolding helped participants systematically examine their noticing practices.

In the reflective reframing phase, the participants revisited the students' work through guided protocols that included comparisons of frames, reflective prompts focusing on shifts in perspective, and peer feedback sessions using structured forms. This phase specifically targeted frame shifting through deliberate practice with alternative interpretive frameworks.

4.2 Participants

Twenty-six of the 34 enrolled prospective secondary mathematics teachers (76.5% response rate) provided consent for their coursework to be included in the study. Informed consent for research participation was obtained after course completion to maintain methodological rigour and minimise potential response bias. This post-course recruitment strategy ensured that the responses were authentic pedagogical work rather than data produced specifically for research purposes, thereby strengthening the ecological validity of the findings.

The participants (16 females, 10 males) were enrolled in a two-year master's degree program in mathematics teacher education. All held bachelor's degrees in mathematics, with teaching experience ranging from none to two years of part-time teaching, positioning them as novices in professional noticing.


4.3 Data collection

The study used a pre-post design, with data collected during the first and last sessions of the two-week course. The

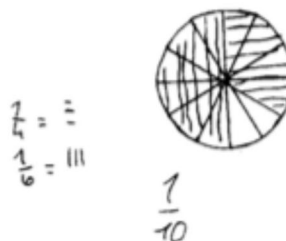
Fig. 3 Noticing task on Taylor's thinking about fractions (based on Hasemann, 1981)

In a lesson on fractions, a fifth-grade class (ages 11–12) was given the following task:

Shade first $\frac{1}{4}$ of the circle and then $\frac{1}{6}$ of the circle.
What fraction of the circle have you shaded in total?



One student, named Taylor, approached the task as follows:



When asked how Taylor solved the task, Taylor explained:

Taylor: First, I shaded 4 twelfths (Taylor points to the horizontal lines in the diagram), then I shaded 6 twelfths (Taylor points to the vertical lines in the diagram). That makes 10 twelfths. So there are ... (Taylor points to the $\frac{1}{10}$ in the diagram).

The teacher then asked Taylor to calculate the task in writing. Taylor wrote:

$$\frac{1}{4} + \frac{1}{6} = \frac{3}{12} + \frac{2}{12} = \frac{5}{12}$$

After completing the written calculation, the teacher asked:

Teacher: What is the answer you found in your written calculation?
Taylor: (Taylor points to the $\frac{5}{12}$ in the written calculation)
Teacher: And what is the answer you found using your diagram?
Taylor: (Taylor points to the $\frac{1}{10}$ in the diagram)
Teacher: Well, yes, but what is the correct answer?
Taylor: Um ... Both are correct ... First, I counted the (Taylor points to the $\frac{1}{10}$ in the diagram), and then I calculated the (Taylor points to the $\frac{5}{12}$ in the written calculation).

primary data source was a noticing task adapted from Hasemann's (1981) research on student thinking about fractions, focusing on a student's (Taylor's) mathematical work (see Fig. 3). This task was selected for its rich potential for multiple analyses, incorporating visual and numerical representations, and interpretability through various theoretical frames.

The participants responded in writing to three structured prompts based on Jacobs et al.'s (2010) professional noticing framework:

- (1) *Attending*: 'What do you find noteworthy about Taylor's mathematical thinking and work?'
- (2) *Interpreting*: 'What can you say about Taylor's mathematical understanding and how do you interpret it?'
- (3) *Deciding how to respond*: 'Supposing you were Taylor's teacher, how would you respond to Taylor?'

Responses were submitted via a secure online platform as part of regular coursework, yielding 156 total entries (26 participants \times 2 time points \times 3 prompts).

Using the same task at both time points provided a controlled context to examine changes in noticing practices and enabled direct comparisons to track participants' development. While task familiarity may have influenced responses, the authentic nature of the data as regular coursework, cou-

pled with retrospective consent, assures that responses reflect genuine professional development rather than task-specific performance effects.

Additionally, participants maintained reflective journals throughout the course, documenting their evolving use of the coding scheme and the influence of frames on their engagement with student thinking. These journals were structured around specific prompts that asked participants to reflect on (1) their initial frames of student thinking, (2) alternative ways they could frame the same student work, (3) how different frames influenced their noticing practices, and (4) challenges they experienced in shifting frames. These journals, serving as a secondary data source, offered valuable insights into the mechanisms underlying changes in noticing practices.

4.4 Data analysis

The analysis combined quantitative and qualitative approaches using the coding scheme developed by Scheiner (2023). This scheme was developed in a previous study with 9 prospective teachers (Scheiner, 2023) and then validated through pilot testing with 7 additional prospective teachers, applying it to different noticing tasks on topics including fractions, probability, and limits. The scheme has also been applied in additional contexts by Güner et al. (2025), suggesting its reliability across various mathematical contexts and research settings.

The coding scheme distinguishes three orientations in teacher noticing: deficit-based (focusing on errors, misconceptions, or inadequacies), strength-based (emphasising capabilities, understanding, or potential), and uncommitted (neither explicitly deficit-based nor strength-based). Each written response served as a unit of analysis, with responses coded separately for attending, interpreting, and responding practices.

For attending, interpreting, and responding practices, we coded for specific aspects (the aspects prospective teachers attended to), stances (the stances prospective teachers took in interpreting student thinking), and instructional moves (the instructional moves prospective teachers suggested in responding to student thinking) across three orientations (deficit-based, strength-based, and uncommitted).

Table 1 provides brief descriptions of these coding categories. Detailed descriptions and examples are provided in the electronic supplementary material (see Tables A, B, and C).

Each aspect, stance, and instructional move was coded for evidence levels:

- 0 (no evidence): the aspect/stance/instructional move was not present;
- 1 (limited evidence): the aspect/stance/instructional move was present but not elaborated upon or only briefly mentioned; and

- 2 (strong evidence): the aspect/stance/instructional move was clearly articulated, elaborated, and supported by examples from the student's work.

For example, in attending, a response such as “Taylor made some errors in his work” received a code of 1 (limited evidence) for the error/mistake aspect, whereas a response stating “Taylor incorrectly identifies the fraction as $1/10$, which does not match his calculation . . . He is not applying the principle of determining the greatest common divisor correctly” received a code of 2 (strong evidence).

Two independent coders analysed all 156 responses. The second coder was not involved in course instruction, providing an additional layer of analytical objectivity. To minimise potential bias, blind coding was employed: coders were not informed whether they were analysing responses from the first or last session. Interrater reliability calculations via Cohen's kappa indicated substantial agreement across noticing practices ($\kappa = .77$ for attending, $\kappa = .74$ for interpreting, and $\kappa = .76$ for responding), suggesting a high level of consistency in the coding process (Miles & Huberman, 1994). Disagreements were resolved through discussion until consensus was reached.

To analyse participants' frames, we examined patterns in their coded responses across attending, interpreting, and responding practices (see Scheiner, 2023). A frame was identified when a consistent orientation (deficit-based, strength-based, or uncommitted) was evident across multiple statements within a participant's response. For example, when a participant predominantly used deficit-based aspects in attending (e.g., “Taylor made several errors in representing fractions”), deficit-based stances in interpreting (e.g., “Taylor's work shows significant misconceptions about fractions”), and deficit-based instructional moves in responding (e.g., “I would correct his misunderstanding of denominators”), this pattern indicated a deficit-based frame. Changes in frames were determined by comparing these patterns between the first and last sessions of the course.

The quantitative analysis focused on the frequencies and proportions of strongly evidenced aspects, stances, and instructional moves (coded as 2) at both time points to capture participants' most substantive and deliberate noticing practices. Multiple aspects, stances, or instructional moves could be strongly evidenced within individual responses. Changes in these proportions between the first and last sessions were analysed to identify patterns in participants' development and shifts in their interpretive frames.²

Qualitative analysis followed Braun and Clarke's (2006) thematic analysis approach, progressing from data famil-

²The term ‘strongly evident’ is used throughout the findings to refer specifically to aspects, stances, or instructional moves that received an evidence level code of 2, indicating these aspects, stances, or instructional moves were clearly articulated and supported with examples from the student's work.

Table 1 Descriptions of coding categories

Noticing practice	Orientation	Category	Description
Attending (Aspect)	Deficit-based	Error/mistake	Focus on incorrect answers or approaches
		Failure	Emphasis on student's inability to accomplish a task
		Lack/gap	Identification of missing knowledge or skills
		Misconception	Reference to conceptual misunderstandings
	Strength-based	Ability	Recognition of specific mathematical capabilities
		Strength	Emphasis on particular mathematical strengths
Interpreting (Stance)	Uncommitted	Student doing	Descriptive observation without evaluation
	Deficit-based	Evaluative-negative	Judgmental assessment emphasising shortcomings
		Expectation-conflict	Assumes contradictions in student's work
		Normative	Comparison to normative standard with focus on deviation
	Strength-based	Evaluative-positive	Assessment that emphasises achievement
		Interpretive-asset-based	Making sense of student thinking in terms of resources and capabilities
	Uncommitted	Interpretive-in their own right	Understanding student thinking on its own terms
		Assumption/inference	Conjecture about student thinking without judgment
Interpretive-non-evaluative		Making sense of student work without evaluation	
Deciding how to respond (Instructional move)	Deficit-based	Challenging misconceptions	Directly addressing perceived conceptual misunderstandings
		Flagging/correcting errors	Pointing out or correcting mistakes without building on thinking
		Preventing obstacles	Intervention to avoid future mistakes
		Redirecting understanding	Replacing student's approach with conventional one
	Strength-based	Accessing understanding	Eliciting student thinking as foundation for learning
		Extending/building upon understanding	Building on existing knowledge towards deeper understanding
		Positive reinforcement	Acknowledging and affirming productive thinking
	Uncommitted	Clarifying student work	Seeking additional information about student thinking
		Giving general response	Offers generic instructional feedback or guidance

iarisation (multiple readings of the data) through theme development (identifying patterns in the coding) and refinement (review of themes against the full dataset). Themes were developed for each noticing practice: attending-related themes captured how participants shifted from deficit-based to strength-based filters and from surface-level observations to deeper engagement with reasoning; interpreting-related themes highlighted transitions from deficit-based to strength-based lenses and from simplistic categorisation to nuanced understanding; and responding-related themes documented movement from error-correction to strength-based guidance and from teacher-centred to student-centred instructional approaches.

Reflective journals served as complementary data to contextualise the primary findings. Journal analysis followed a focused reading approach (Maxwell, 2013) guided by specific analytical questions: (1) How do participants describe changes in their noticing practices? (2) What mechanisms do they identify as supporting these changes? (3) How do they connect these changes to their developing professional identities? This selective analysis allowed the journal data

to provide an explanatory context for the observed shifts in noticing practices while maintaining an analytical focus on the primary data sources.

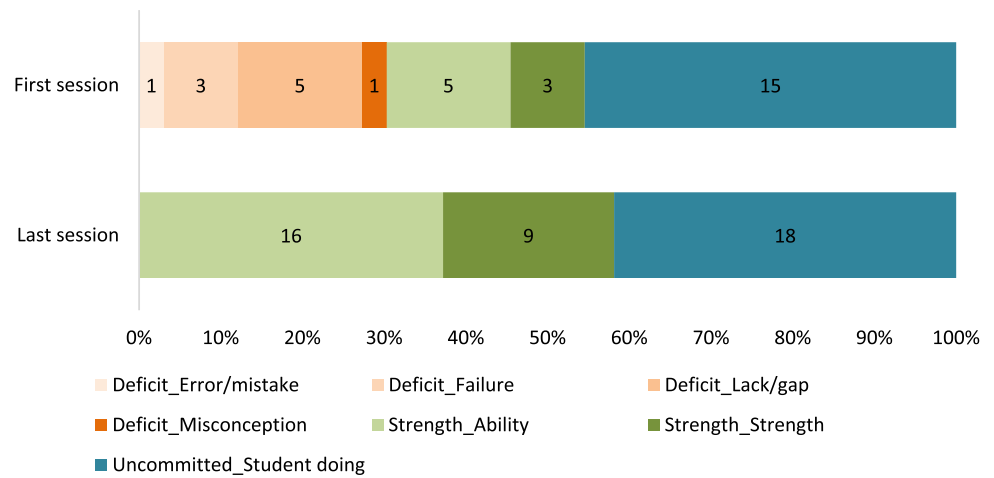
From the participant pool, two prospective teachers—referred to as Ari and Sam—were selected as illustrative cases based on (a) the completeness of their journals, (b) detailed documentation of their frame-shifting experiences, and (c) representativeness of broader patterns observed in the dataset. These cases were selected after completing the primary analysis to ensure that they reflected typical rather than exceptional trajectories of development.

Data analysis was conducted in German to preserve the nuances of the participants' responses. Translations were provided for excerpts included in this study to ensure accessibility for an international audience.

5 Results

The analysis revealed consistent patterns across attending, interpreting, and responding practices. The quantitative find-

Fig. 4 Changes in aspects highlighted in attending to student thinking. *Note.* Counts and proportions reflect strongly evidenced aspects (coded as 2). Multiple aspects could be evident in a single response. Percentages calculated as proportion of total strongly evidenced instances at each time point



ings focus exclusively on strongly evidenced orientations (coded as 2), which represent participants’ most substantive and deliberate noticing practices, providing the clearest indicators of their underlying interpretative frameworks. There were observed decreases in strongly evidenced deficit-based orientations across all three noticing practices, dropping from 30.3% to 0% in attending, 50.0% to 7.0% in interpreting, and 47.1% to 9.3% in responding. Strongly evidenced strength-based orientations showed increases in all noticing practices, increasing from 24.2% to 58.1% in attending, 23.7% to 62.8% in interpreting, and 38.2% to 76.7% in responding. Strongly evidenced uncommitted orientations remained relatively stable across noticing practices, suggesting that participants were developing specific, interpretive frames rather than simply becoming more neutral.

These patterns indicate a profound shift in how participants approached student mathematical thinking—moving from predominantly deficit-based frames towards strength-based frames that recognised and built upon student capabilities. The following subsections examine these changes in greater detail for each noticing practice.³

5.1 Changes in participants’ attending to students’ mathematical thinking

5.1.1 Quantitative changes

Analysis of deficit-based, strength-based, and uncommitted aspects revealed significant shifts in participants’ attending practices between the first and last sessions (see

³Direct quotations from the noticing task responses of two prospective teachers (Ari and Sam) appear under thematic subheadings of qualitative transformations (with complete responses available in Tables D and E in the electronic supplementary material), while reflections drawn from their journals appear under ‘Reflective insights’ subheadings. This organisation distinguishes between data showing evidence of changed practices and data explaining participants’ awareness of these changes.

Fig. 4). Initially, deficit-based attending was strongly evident in 30.3% of the coded instances, with participants focusing on conceptual gaps, errors, or failures. By the last session, no deficit-based aspects were strongly evident, indicating a complete shift away from deficit-based observation.

Strong evidence for strength-based attending increased substantially from 24.2% to 58.1%, reflecting a growing focus on recognising and affirming students’ mathematical abilities. Uncommitted attending represented the largest proportion, initially at 45.5%. While the absolute count increased, its proportion slightly decreased to 41.9% in the last session. These responses typically comprised descriptive observations that neither critiqued nor affirmed student work.

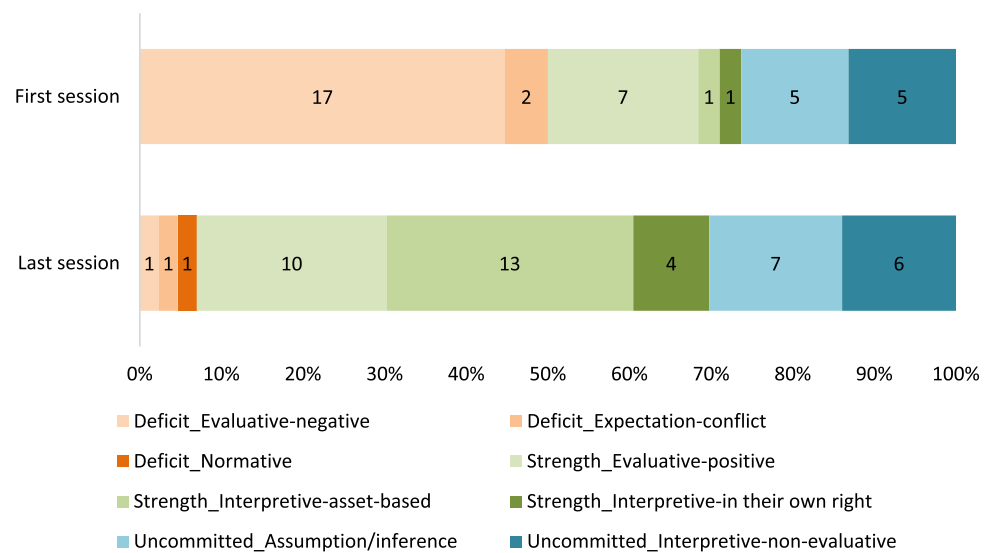
5.1.2 Qualitative transformations

Two major qualitative shifts emerged in the participants’ attending practices:

From deficit-based to strength-based filters. While uncommitted responses were most common initially, a substantial portion of the responses (30.3%) focused on deficits. For example, in the first session, Ari noted, “Taylor does not draw the correct number of twelfths when representing the fractions as parts of the circle ... he misinterprets the denominator of the quarter or the sixth (and the tenth) as the number of twelfths.” Similarly, Sam highlighted perceived failures, remarking, “Taylor was unable to differentiate between numerators and denominators in his drawings and did not make the fractions equal before drawing them.”

In contrast, the final session responses adopted strength-based filters. Ari recognised the student’s approach to visual representation, noting, “What is remarkable about Taylor’s mathematical thinking is that he shaded the two fractions as parts of a circle, assigning a different shading style to each fraction. It is also clever that he added a legend to explain the shading styles.” Sam acknowledged the student’s systematic approach, observing, “By shading the two fractions

Fig. 5 Changes in stances taken in interpreting student thinking. *Note.* Counts and proportions reflect strongly evidenced stances (coded as 2). Multiple stances could be evident in a single response. Percentages calculated as proportion of total strongly evidenced instances at each time point



differently, he demonstrated structured thinking.” This shift reflects prospective teachers’ ability to apply alternative interpretive frames that recognise and value student strengths.

From surface-level observations to deeper engagement with reasoning. Early responses focused on visible issues without exploring reasoning. Ari noted, “Taylor does not recognise that both problems represent the same task or ... he assumes that one task can have two different solutions”, whereas Sam remarked, “[Taylor] did not realise that he arrived at two different solutions and could not distinguish between the correct and incorrect answers.”

The final session responses reflected deeper engagement with reasoning, indicating a shift towards frames that valued understanding student thinking on its own terms. Ari noted the internal coherence of the student’s reasoning: “In explaining how he solved the problem, Taylor interpreted the denominator of $1/4$ and $1/6$ as the number of twelfths and, based on this assumption, logically derived the quantities. He coherently noted the result as $1/10$.” Sam similarly engaged with the student’s approach: “Taylor identified $1/4$ as four parts of the whole and drew this according to his understanding. He did the same with $1/6$. He translated $1/4$ into four twelfths. Similarly, he translated $1/6$ into six twelfths. He then added the shaded parts and arrived at ten twelfths, which he consistently expressed as 1 over 10 or $1/10$.”

5.1.3 Reflective insights

The participants’ reflective journals provided further evidence for these transformations. For example, Ari observed, “I have realised I used to immediately look for what was wrong. Now I find myself first trying to understand the student’s reasoning, looking for the mathematical thinking behind [their] approach.”

Sam’s reflection captured the essence of frame shifting: “It is not just about seeing different things; it is about seeing the same things differently. Before, I marked Taylor’s [visual] approach as wrong; now, I see it as an entry point into his thinking.”

5.2 Changes in participants’ interpretations of students’ mathematical thinking

5.2.1 Quantitative changes

Analysis of deficit-based, strength-based, and uncommitted stances revealed significant shifts in participants’ interpreting practices (see Fig. 5). Initially, deficit-based interpretation accounted for 50.0% of strongly evidenced instances, focusing predominantly on negative evaluations. By the final session, this percentage dropped sharply to 7.0%, indicating a deliberate move away from deficit-based frames.

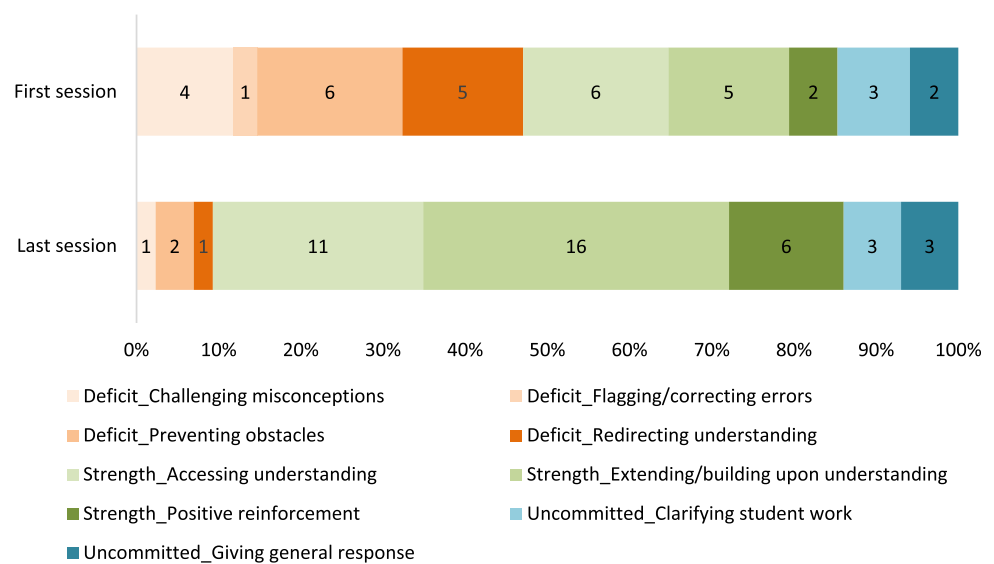
Strong evidence for strength-based interpretation increased substantially from 23.7% to 62.8%. This growth reflected a clear shift towards frames that emphasise student capabilities, with a notable increase in asset-based, interpretive stances. Uncommitted interpreting represented 26.3% of strongly evidenced instances initially, rising slightly to 30.2% in the last session, indicating the persistent presence of neutral or descriptive interpretations alongside the growth in strength-based frames.

5.2.2 Qualitative transformations

Two major qualitative shifts emerged in participants’ interpreting practices:

From deficit-based to strength-based lenses. Initially, participants interpreted students’ work through deficit-based lenses that emphasised gaps and errors. For example, Ari

Fig. 6 Changes in instructional moves proposed in decisions on how to respond to student thinking. *Note.* Counts and proportions reflect strongly evidenced instructional moves (coded as 2). Multiple instructional moves could be evident in a single response. Percentages calculated as proportion of total strongly evidenced instances at each time point



remarked, “[Taylor] does not grasp the roles of the numerator and denominator, which suggests he has not developed a conceptual understanding of fractions.” Sam interpreted procedural success negatively: “Taylor applies automated steps without understanding the underlying concepts, as shown by his inability to distinguish between correct and incorrect solutions.”

By the final session, the participants had shifted to strength-based lenses that highlighted mathematical potential. Ari noted, “[Taylor’s] logical approach to aligning denominators and adding fractions shows procedural fluency and emerging understanding, even if his interpretation of denominators is incomplete.” Similarly, Sam reframed their interpretation, stating, “Taylor’s structured thinking and consistent execution of visual and written solutions show a foundation for further conceptual growth.”

From simplistic categorisation to nuanced understanding. Initial interpretations often relied on binary frames that categorised work as simply correct and incorrect, with limited exploration of the reasoning behind student approaches. Ari initially concluded, “[Taylor] does not understand that the two tasks represent the same problem,” reducing the student’s work to a lack of comprehension. Similarly, Sam asserted, “[Taylor’s] reliance on automated rules prevents him from adapting to unfamiliar problems,” focusing on surface-level assessment rather than engaging with the student’s thought process.

The final session responses revealed what appeared to be a more nuanced frame of student thinking that engaged deeply with reasoning. Ari acknowledged contextuality, stating, “Taylor’s view of the tasks as distinct may stem from his focus on their differing representations rather than a lack of understanding of equivalence.” Similarly, Sam offered a more complex interpretation that recognised developmental progression: “Taylor’s logical process in representing 1/4

and 1/6 suggests that he is developing an understanding of how fractions relate to parts of a whole.”

5.2.3 Reflective insights

The participants’ journals highlighted their evolving interpretive frames. Ari reflected, “Looking back at my early responses, I am struck by how quickly I was to judge student work. Now I try to understand [their] approach, asking myself what understanding this work reveals before considering how it differs from traditional approaches.”

Sam captured a similar transformation: “Probably the most profound change for me was realising that what looks like misunderstanding at first often has consistent logic. I have learned to suspend judgement and instead dig into the reasoning.”

5.3 Changes in participants’ decisions about how to respond to students’ mathematical thinking

5.3.1 Quantitative changes

Analysis of deficit-based, strength-based, and uncommitted instructional moves revealed significant shifts in participants’ responding practices (see Fig. 6). Deficit-based responding, which was strongly evident in 47.1% of the initial coded instances and focused particularly on preventing perceived learning obstacles or redirecting understanding, decreased markedly to 9.3% in the final session.

Strong evidence for strength-based responding increased substantially from 38.2% to 76.7%, reflecting a shift towards frames that prioritise instructional moves to access and leverage students’ mathematical strengths. Uncommitted responding remained relatively stable, representing 14.7% of strongly evidenced instances in the first session and 14.0%

in the last session. These responses typically involved non-specific or neutral instructional moves that neither directly addressed deficits nor explicitly built on strengths.

5.3.2 Qualitative transformations

Two major qualitative shifts emerged in the participants' responding practices:

From error-correction to strength-based guidance. Initial responses were framed around correcting errors, with little attention given to leveraging students' strengths. Ari's early response positioned the student's approach as deficient and in need of correction: "I would explain again that the denominator shows how many parts the whole is divided into and use visual aids to illustrate this concept." Similarly, Sam emphasised correction: "I would have Taylor redraw the circles to correctly represent $1/4$ and $1/6$, ensuring he understands how to represent the fractions visually."

In the final session, the responses shifted to frames that positioned student work as a foundation for learning. Ari validated the student's efforts: "I would highlight how Taylor's legend effectively clarifies his reasoning and use this as a starting point to discuss how visual representations connect to calculations." Sam also leveraged the student's understanding to guide learning: "Taylor's ability to align fractions shows his progress; I would encourage him to explore how this relates to equivalence."

From teacher-centred to student-centred instruction. The initial responses emphasised teacher-led instruction with limited student agency. Ari stated, "I would explain why his solutions differ and demonstrate how to correctly align the fractions using visual aids." Sam similarly focused on teacher direction: "I would show Taylor how to divide a circle into equivalent parts and explain why the denominators need to match."

The final session responses appeared to be framed through perspectives that valued student thinking and dialogic engagement. Ari encouraged reflective dialogue: "I would ask him [Taylor] to verify whether a quarter of a circle truly equals three twelfths of a circle and make a connection to the calculation." Similarly, Sam invited student reasoning, asking, "What does the shading in your diagram tell us about the fractions you added? Can you explain how the numbers relate to the parts you drew?" These responses fostered meaningful mathematical discourse, reflecting a frame that positioned students as active participants in knowledge construction.

5.3.3 Reflective insights

The participants' journals documented their evolving frames for instruction. Ari reflected, "I used to think good teaching meant explaining the procedure step by step. Now I see how

much more powerful it is to start with students' existing understanding and build from there."

Similarly, Sam noted, "One change for me has been learning to pause before reacting. Instead of jumping in with corrections, I now try to understand the potential [in students' thinking] and use that as a basis for learning."

5.4 Mechanisms supporting change in teachers' noticing practices

The coding scheme emerged as a pivotal mechanism for transformation, serving analytical and pedagogical functions while facilitating the translation between the research and practice domains. The participants' reflective journals highlighted their growing awareness of how the coding scheme helped them identify and challenge default orientations. For example, Ari noted, "Using the coding scheme to analyse my [initial] responses made me realise how automatically I focused on what students could not do rather than what they could."

In attending practices, the scheme's explicit distinction between deficit-based aspects (errors, gaps, misconceptions) and strength-based aspects (abilities, strengths) appeared to help participants redirect their focus. The complete elimination of strongly evidenced deficit-based attending (from 30.3% to 0%) highlights how these categories may have enabled participants to consciously prioritise students' capabilities. As Ari described, "I started looking for strengths first, before noting any challenges. . . . The coding scheme gave me specific things I could look for."

In interpreting practices, the detailed breakdown of stances appeared to support participants in understanding how their interpretive frames shaped their sense-making of student thinking. The increase in strength-based interpretation (23.7% to 62.8%) may reflect the scheme's role in facilitating this shift. Sam reflected, "Revisiting my interpretation of Taylor's approach, I realised that focusing on what he understood allowed me to appreciate the logic behind his answer, rather than dismissing it as incorrect."

In responding practices, the scheme's categorisation of instructional moves offered concrete alternatives to deficit-based teaching approaches. The rise in strength-based responding (38.2% to 76.7%) suggests that explicit articulation of alternatives may have enabled participants to envision more constructive responses. As Sam noted, "The coding showed me that instead of just correcting his [Taylor's] approach, I could build on his understanding."

In addition to these mechanisms, three additional processes appeared to support frame shifting. First, collaborative analysis created opportunities for social mediation through structured protocols. The participants engaged in systematic peer discussions using coding sheets that required them to justify their interpretations and consider alternative perspectives. For example, Sam's journal noted,

“When my group discussed whether Taylor’s 1/10 showed misconception or logical thinking, I realised that my initial interpretation was too limited.” Second, structured reflection prompted systematic comparisons of different frames. The participants completed analytical matrices contrasting deficit-based and strength-based framings of the same student work. Ari reflected: “The comparison prompted me to find strengths in [student] work I initially dismissed as wrong.” Third, repeated practice with frame shifting across multiple student work samples appeared to enable progressive integration. The participants analysed three different student work samples (fractions, probabilities, limits) using the coding scheme, developing increasing facilities with strength-based framing. As documented in participants’ journals, this repetition fostered what Ari called “a new professional mindset.”

6 Discussion and conclusion

This study revealed substantial transformations in prospective mathematics teachers’ noticing practices, illustrating how structured frame shifting fosters more inclusive teaching practices.

6.1 Frame shifting as a mechanism for transformative noticing

The findings of this study suggest frame shifting as a potentially powerful mechanism for transforming teacher noticing in three key dimensions:

First, this study offers insights into how frames function as both filters and lenses (e.g., Sherin & Russ, 2014).⁴ As filters, frames appeared to influence what participants attended to (e.g., with deficit frames initially directing attention towards errors and gaps while rendering strengths invisible). As lenses, frames appeared to shape how participants interpreted what they observed (e.g., with deficit lenses initially interpreting student work primarily in terms of deviation from normative expectations). The coding scheme made these framing processes visible to participants, allowing them to recognise how their frames shaped their professional noticing (see Russ & Luna, 2013). The observed reduction in deficit-based orientations suggests how making implicit frames explicit may enable participants to consciously shift their attention, interpretation, and instructional decision-making.

Second, the findings illuminate the socially mediated nature of frame shifting. While frame shifting has often been

conceptualised as an individual cognitive process (Hammer et al., 2005), our results suggest how it may be facilitated through collaborative social practices. The collaborative analysis phase of the course design created a ‘professional community of practice’ in which new ways of seeing were collectively developed and validated (Goodwin, 1994). This social dimension aligns with Sherin and van Es’ (2009) finding that noticing develops through participation in discourse communities where teachers negotiate shared understandings of what is noteworthy in student work.

Third, the findings provide insights into the relationship between frame shifting and the development of more equitable noticing practices. As participants deliberately practised transitioning from deficit-based frames to strength-based frames, they cultivated what Louie (2018) described as ‘inclusive framing’—approaches to mathematical activity and ability that foster equity and inclusion in mathematics education. This transformation advances equitable mathematics teaching by enabling teachers to recognise mathematical competence in its diverse manifestations rather than limiting recognition to expressions that merely conform to normative expectations.

6.2 Implications for teacher education design

The analysis suggests three transformative design principles that bridge the gap between theoretical understanding and practical implementation of strength-based noticing.

First, developing strength-based practices requires structural support mechanisms that render interpretive frames both visible and actionable. The findings suggest that explicit analytical tools, particularly structured coding schemes, function as crucial mediating artefacts in professional development. These tools support prospective teachers in systematically deconstructing their own noticing practices, thereby facilitating conscious reconstruction of their interpretive frameworks.

Second, frame shifting benefits from carefully orchestrated learning trajectories that scaffold teachers through progressive stages of professional transformation. This study identifies three essential components: (a) structured protocols for collaborative analysis of student work that create social spaces for negotiating alternative interpretations; (b) guided practice in conscious reframing that challenges entrenched deficit perspectives; and (c) opportunities to develop and refine alternative instructional responses aligned with strength-based orientations.

Third, reflective practices need to be more structured and focused than traditional approaches are (Liu, 2015), incorporating structured protocols that explicitly target frame examination. The study suggests that guided reflection, when strategically focused on frame awareness and reconstruction, may support deeper professional learning. This principle contributes to understanding how individual cognitive

⁴I am grateful to one of the reviewers for pointing out this dual nature of frames.

transformation interfaces with collective professional development, suggesting that frame-focused reflection serves as a critical bridge between personal insight and professional practice change.

6.3 Limitations and future research

Several limitations warrant consideration and point to directions for future research:

First, using identical noticing tasks at both time points enabled direct comparisons of noticing practices but may have introduced task familiarity effects. While familiarity may have influenced surface-level responses, the depth and nature of observed changes—particularly the shifts in interpretive frames documented—suggest genuine transformative learning rather than task-specific adaptation. The authentic nature of the data—collected as regular coursework with retrospective consent—helps mitigate concerns about social desirability bias by maintaining ecological validity. Future studies might benefit from incorporating varied tasks while maintaining this separation between pedagogical and research contexts.

Second, the dual role of the author as instructor and researcher necessitates critical examination. While this positionality provided valuable insights into pedagogical mechanisms, it potentially introduced power dynamics and social desirability bias despite methodological safeguards (retrospective consent, blind coding, and triangulation). Future research should implement independent researcher designs where the instructor and analytical roles are separated, allowing for examination of whether similar transformative patterns emerge absent the potential influence of instructor–researcher dynamics. Also, cross-institutional comparative analyses would be valuable for examining how frame shifting processes manifest across diverse educational contexts where researcher positionality varies, thereby isolating the effects of instructor influence from the pedagogical intervention itself. Such methodological diversification would strengthen the validity of findings while preserving the ecological authenticity that characterises practice-embedded research.

Third, the reliance on written student artifacts, while providing analytical clarity, fundamentally differs from video-based noticing instruments (see Santagata et al., 2021; Weyers et al., 2023). This methodological choice constrains observational complexity, privileging interpretive analysis over the attentional demands characteristic of authentic classroom contexts (e.g., reducing multimodal information processing). Moreover, the translation of the observed changes in teachers' written responses to dynamic classroom practice remains unexamined. Future research should explore how teachers implement these shifts in practice and what support is needed to sustain them in authentic classroom settings.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11858-025-01715-x>.

Funding Information Open Access funding enabled and organized by Projekt DEAL.

Availability of data and material The data used in this study are not publicly available due to informed consent provided by the participants. Requests to access the dataset should be directed to the author.

Declarations

Competing Interests The author declares no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Adiredja, A. P., & Louie, N. (2020). Understanding the web of deficit discourse in mathematics education. *For the Learning of Mathematics*, 40(1), 42–46.
- Aguirre, J., Mayfield-Ingram, K., & Martin, D. (2013). *The impact of identity in K-8 mathematics: Rethinking equity-based practices*. National Council of Teachers of Mathematics.
- Amador, J. M., Bragelman, J., & Superfine, A. C. (2021). Prospective teachers' noticing: A literature review of methodological approaches to support and analyze noticing. *Teaching and Teacher Education*, 99, 103256. <https://doi.org/10.1016/j.tate.2020.103256>.
- Boaler, J. (2022). *Mathematical mindsets: Unleashing students' potential through creative mathematics, inspiring messages and innovative teaching* (2nd ed.). Jossey-Bass.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>.
- Cochran-Smith, M., & Lytle, S. L. (2009). *Inquiry as stance: Practitioner research for the next generation*. Teachers College Press.
- Crespo, S. (2000). Seeing more than right and wrong answers: Prospective teachers' interpretations of students' mathematical work. *Journal of Mathematics Teacher Education*, 3(2), 155–181. <https://doi.org/10.1023/A:1009999016764>.
- Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education*, 27(4), 403–434. <https://doi.org/10.5951/jresmetheduc.27.4.0403>.
- Goffman, E. (1974). *Frame analysis: An essay on the organization of experience*. Northeastern University Press.
- Goodwin, C. (1994). Professional vision. *American Anthropologist*, 96(3), 606–633. <https://doi.org/10.1525/aa.1994.96.3.02a00100>.

- Güner, P., Bozkuş, F., & Güler, M. (2025). To notice, but what? An investigation on pre-service teachers' noticing of strengths and deficits in student thinking. *Teaching and Teacher Education*, *160*, 105035. <https://doi.org/10.1016/j.tate.2025.105035>.
- Gutiérrez, R. (2013). The sociopolitical turn in mathematics education. *Journal for Research in Mathematics Education*, *44*(1), 37–68. <https://doi.org/10.5951/jresmetheduc.44.1.0037>.
- Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 89–120). Information Age Publishing.
- Hand, V. (2012). Seeing culture and power in mathematical learning: Toward a model of equitable instruction. *Educational Studies in Mathematics*, *80*(1), 233–247. <https://doi.org/10.1007/s10649-012-9387-9>.
- Hasemann, K. (1981). On difficulties with fractions. *Educational Studies in Mathematics*, *12*(1), 71–87. <https://doi.org/10.1007/BF00386047>.
- Jacobs, V. R., & Empson, S. B. (2016). Responding to children's mathematical thinking in the moment: An emerging framework of teaching moves. *ZDM – Mathematics Education*, *48*(1), 185–197. <https://doi.org/10.1007/s11858-015-0717-0>.
- Jacobs, V. R., Lamb, L. L., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for Research in Mathematics Education*, *41*(2), 169–202. <https://doi.org/10.5951/jresmetheduc.41.2.0169>.
- Jilk, L. M. (2016). Supporting teacher noticing of students' mathematical strengths. *Mathematics Teacher Educator*, *4*(2), 188–199. <https://doi.org/10.5951/mathteacheduc.4.2.0188>.
- Kalinec-Craig, C. A., Bannister, N., Bowen, D., Jacques, L. A., & Crespo, S. (2021). "It was smart when:" supporting prospective teachers' noticing of students' mathematical strengths. *Journal of Mathematics Teacher Education*, *24*(4), 375–398. <https://doi.org/10.1007/s10857-020-09464-2>.
- König, J., Santagata, R., Scheiner, T., Adleff, A.-K., Yang, X., & Kaiser, G. (2022). Teacher noticing: A systematic literature review on conceptualizations, research designs, and findings on learning to notice. *Educational Research Review*, *36*, 100453. <https://doi.org/10.1016/j.edurev.2022.100453>.
- Liu, K. (2015). Critical reflection as a framework for transformative learning in teacher education. *Educational Review*, *67*(2), 135–157. <https://doi.org/10.1080/00131911.2013.839546>.
- Louie, N. L. (2017). The culture of exclusion in mathematics education and its persistence in equity-oriented teaching. *Journal for Research in Mathematics Education*, *48*(5), 488–519. <https://doi.org/10.5951/jresmetheduc.48.5.0488>.
- Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics*, *97*(1), 55–69. <https://doi.org/10.1007/s10649-017-9775-2>.
- Louie, N. L., Adiredja, A. P., & Jessup, N. (2021). Teacher noticing from a sociopolitical perspective: The FAIR framework for anti-deficit noticing. *ZDM – Mathematics Education*, *53*(1), 95–107. <https://doi.org/10.1007/s11858-021-01229-2>.
- Mason, J. (2002). *Researching your own practice: The discipline of noticing*. Routledge.
- Mason, J. (2011). Noticing: Roots and branches. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 35–50). Routledge.
- Maxwell, J. A. (2013). *Qualitative research design: An interactive approach* (3rd ed.). Sage.
- Mendez, J. A., & van Es, E. A. (2024). Examining teachers' relational noticing: Promoting equity through positive interactions in mathematics education. *Journal of Mathematics Teacher Education*, *1*–26. <https://doi.org/10.1007/s10857-024-09635-5>.
- Mezirow, J. (2000). *Learning as transformation: Critical perspectives on a theory in progress*. Jossey-Bass.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Sage.
- Othmann, T., Scheiner, T., & Lutz-Westphal, B. (2025). Exploring teachers' identification of qualities in students' mathematical thinking. *Research in Mathematics Education*. <https://doi.org/10.1080/14794802.2025.2491103>.
- Patterson Williams, A. D., Athanases, S. Z., Higgs, J., & Martinez, D. C. (2020). Developing an inner witness to notice for equity in the fleeting moments of talk for content learning. *Equity & Excellence in Education*, *53*(4), 504–517. <https://doi.org/10.1080/10665684.2020.1791282>.
- Rubin, E., & van Es, E. A. (2023). "My noticing lens disrupts this narrative": Preservice mathematics teachers' awareness of the self as noticer. *School Science and Mathematics*, *123*(8), 476–487. <https://doi.org/10.1111/ssm.12618>.
- Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, *50*(3), 284–314. <https://doi.org/10.1002/tea.21063>.
- Santagata, R., König, J., Scheiner, T., Nguyen, H., Adleff, A.-K., Yang, X., & Kaiser, G. (2021). Mathematics teacher learning to notice: A systematic review of studies of video-based programs. *ZDM – Mathematics Education*, *53*(1), 119–134. <https://doi.org/10.1007/s11858-020-01216-z>.
- Scheiner, T. (2021). Towards a more comprehensive model of teacher noticing. *ZDM – Mathematics Education*, *53*(1), 85–94. <https://doi.org/10.1007/s11858-020-01202-5>.
- Scheiner, T. (2023). Shifting the ways prospective teachers frame and notice student mathematical thinking: From deficits to strengths. *Educational Studies in Mathematics*, *114*(1), 35–62. <https://doi.org/10.1007/s10649-023-10235-y>.
- Scheiner, T., & Montes, M. A. (2024). Exploring prospective teachers' stances in making sense of students' mathematical ideas. *Journal of Mathematics Teacher Education*. <https://doi.org/10.1007/s10857-024-09639-1>.
- Schoenfeld, A. H. (2011). Noticing matters. A lot. Now what? In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 223–238). Routledge.
- Shah, N., & Coles, J. A. (2020). Preparing teachers to notice race in classrooms: Contextualizing the competencies of preservice teachers with antiracist inclinations. *Journal of Teacher Education*, *71*(5), 584–599. <https://doi.org/10.1177/0022487119900204>.
- Sherin, M. G., Jacobs, V. R., & Philipp, R. A. (2011). Situating the study of teacher noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 1–13). Routledge.
- Sherin, M. G., & Russ, R. S. (2014). Teacher noticing via video: The role of interpretive frames. In B. Calandra & P. Rich (Eds.), *Digital video for teacher education: Research and practice* (pp. 11–28). Routledge.
- Sherin, M. G., & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education*, *60*(1), 20–37. <https://doi.org/10.1177/0022487108328155>.
- Stockero, S. L., Van Zoest, L. R., Freeburn, B., Peterson, B. E., & Leatham, K. R. (2022). Teachers' responses to instances of student mathematical thinking with varied potential to support student learning. *Mathematics Education Research Journal*, *34*, 165–187. <https://doi.org/10.1007/s13394-020-00334-x>.
- van Es, E. A., Hand, V., Agarwal, P., & Sandoval, C. (2022). Multidimensional noticing for equity: Theorizing mathematics teachers' systems of noticing to disrupt inequities. *Journal for Research in Mathematics Education*, *53*(2), 114–132. <https://doi.org/10.5951/jresmetheduc-2019-0018>.

- van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education*, 10(4), 571–596.
- Walsh, M. E., & Schunn, C. D. (2025). Reconceptualizing framing theory for adaptive teaching expertise: The role of strategic and expansive framing. *Educational Psychologist*, 1–18. <https://doi.org/10.1080/00461520.2025.2486107>.
- Weyers, J., König, J., Santagata, R., Scheiner, T., & Kaiser, G. (2023). Measuring teacher noticing: A scoping review of standardized instruments. *Teaching and Teacher Education*, 122, 103970. <https://doi.org/10.1016/j.tate.2022.103970>.
- Weyers, J., König, J., Scheiner, T., Santagata, R., & Kaiser, G. (2024). Teacher noticing in mathematics education: A review of recent developments. *ZDM – Mathematics Education*, 56(2), 249–264. <https://doi.org/10.1007/s11858-023-01527-x>.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.