

Electronic Journal for Research in **Science & Mathematics Education**

*Flagship Journal of the International Consortium for
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Volume 30 No. 3 | Fall 2026

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Developing Global Competency Skills Among Preservice Childhood Educators Using Diverse Children's Storybooks

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ABSTRACT

The cultural and linguistic diversity of PreK-6 students in the regional school districts surrounding our universities has been increasing over the years, yet existing teacher education programs often address global competency in elementary STEM contexts only at surface levels or as isolated add-ons. This action research study targets the development of global competency skills among undergraduate preservice teachers through redesigned STEM education methods courses. Global competency skills encompass the knowledge, skills, attitudes, and values needed to understand and engage with a diverse and interconnected world, fostering critical thinking, empathy, and effective communication across cultures. Preservice teachers (N=111) participated in modeled inquiry-based STEM lessons integrating children's storybooks with diverse ethnic, cultural, linguistic, or ability-diverse representation. These storybooks served as vehicles for exploring science concepts while broadening teachers' understanding of global diversity. Each lesson aligned with the United Nations Sustainable Development Goals, encouraging consideration of values, beliefs, resources, and practices from different cultural contexts. Data were collected through pre- and post-surveys across two semesters. Quantitative analysis revealed significant findings for four of five questions, showing growth in self-analysis of global competency skills. Qualitative analysis revealed shifts from surface-level cultural awareness to deeper pedagogical understanding, increased family and community engagement considerations, and movement toward lifelong learning orientations. The findings suggest that integrating global competency development within undergraduate STEM methods courses using accessible tools like diverse children's storybooks can effectively inform global dispositions and competencies among future teachers.

Keywords: Culturally responsive pedagogy, teacher education, children's literature, inquiry-based learning, sustainable development goals, diversity and inclusion

Introduction

The cultural and linguistic diversity of PreK-6 students in the regional school districts surrounding our universities has been increasing over recent years, yet existing teacher education programs often address global competency in elementary STEM contexts only at surface levels or as isolated add-ons (Thomas, 2021; Witt, 2023). We redesigned the elementary STEM (Science, Technology, Engineering, Mathematics) education methods courses for our preservice teachers (PSTs) to better prepare them for the students they will serve by enhancing the curriculum with intentionally introduced concepts and practices that would help educators communicate across cultures, recognize their own perceptions, think critically about global issues, and develop efficacy as global citizens. Our hope is that this integration would move beyond superficial cultural awareness toward authentic pedagogical transformation.

Specifically, this action research study examines the development of global competency skills among undergraduate PSTs. Global competency skills encompass the knowledge, skills, attitudes, and

values needed to understand and engage with a diverse and interconnected world, fostering critical thinking, empathy, and effective communication across cultures (Kopish, 2017; Longview Foundation & Learn NC, 2014; UNESCO, 2015).

Developing stronger global competencies helps to prepare teachers to have instructional practices that recognize the interconnectedness of the world (Thomas, 2021; UNESCO, 2015). Students were engaged in an internationalization of science education (ISE) intervention that aimed at increasing their global competency knowledge, skills, and dispositions throughout the semester. The ISE intervention included:

1. Several modeled inquiry-based STEM lessons to develop a classroom culture of wonder, curiosity, learning through questioning,
2. The use of storybooks with diverse representation of cultures and different geographical locations around the world,
3. Deliberate conversations throughout the modeled STEM lessons about cultures to build awareness and empathy.

Research Questions

How does participation in the ISE intervention influence elementary preservice teachers'?

- a. Global competencies (knowledge, skills, and dispositions),
- b. Future classroom environment design, and
- c. Instructional design choices.

Conceptual Anchoring and Literature Review

Global Competencies have emerged as essential elements in preparing individuals to navigate and contribute to an increasingly interconnected world. Global competence is defined as having the dispositions and capacity to understand and take action on issues of global significance (Kopish, 2017). The PISA framework (OECD, 2019) expands this definition to:

A multidimensional capacity that encompasses the ability to: 1) examine issues of local, global, and cultural significance; 2) understand and appreciate the perspectives and worldviews of other; 3) engage in open, appropriate, and effective interactions across cultures, and 4) take action for collective well-being and sustainable development.” (Boix-Mansilla & Schleicher, 2022, p. 11)

Teaching global competencies is also often referred to as teaching global citizenship, which is broadly defined as the education and cultivation of civic-minded individuals within a global context, emphasizing inclusivity, peace, and sustainability (Thomas, 2021; Byker, 2018). The United Nations Educational, Scientific, and Cultural Organization (UNESCO, 2015) offers a framework for global citizenship that is multifaceted, integrating cognitive, socioemotional, and behavioral dimensions to foster critical thinking about inequities, empathy, communication skills, and collective action for the global good. Furthermore, UNESCO helped to frame the 2030 Agenda for Sustainable Development and led to the creation of 17 sustainable development goals (SDGs), which are an urgent call for all countries in a global partnership (United Nations, 2018). These SDGs include ideas such as global solidarity, inclusion, climate action, anti-discrimination, gender equality and accountability. However, while there is a growing demand for global competencies and these achieving SDGs, particularly in response to global crises such as COVID-19, the teaching of these concepts remains inconsistent, with many college courses addressing them only at a surface level (Thomas, 2021). A significant

challenge lies in ensuring that teaching global competencies promotes justice-oriented citizenship rather than serving a privileged international agenda (Thomas, 2021).

The Globally Competent Teaching Continuum (Longview Foundation & Learn NC, 2014), or GCTC, breaks down these global competencies into three categories: Dispositions, Knowledge, and Skills. Teacher Dispositions include empathy and valuing multiple perspectives, and commitment to promoting equity worldwide. Teacher Knowledge includes understanding global current events, understanding interconnectedness, experiential understanding of cultures, and understanding of intercultural communication. Teacher Skills include communication in multiple languages, creating a classroom environment that values diversity and global engagement, creating learning experiences that promote content-aligned explorations worldwide, facilitate international dialogue that promotes active listening, develop partnerships that have real-world contexts for global learning, and develop and use methods of inquiry to assess students' global competence. This GCTC tool can aid us in reflecting on our global competency abilities as educators and can also assist us with developing and reviewing educational programs designed to achieve growth in global competencies among stakeholders.

Efforts to develop global competencies in education have taken many forms. Study abroad programs have shown to be an exceptionally strong tool for developing global competency skills among preservice teachers (Byker, 2018). This immersive process has also aided in developing intercultural awareness and cultural responsiveness by experiencing a shared common humanity. Study abroad programs, aligned with UNESCO's framework, focus on inclusiveness, peace, and sustainability by supporting three dimensions in our preservice teacher's development: cognitive, socioemotional, and behavioral. The cognitive dimension allows for the critical examination of inequities, the socioemotional dimension focuses on the development of communication skills, respect for diversity, and empathy. Lastly, the behavioral dimension focuses on action, supporting the collective good through collaboration. The challenge with relying on study abroad experiences to develop these skills in our preservice teachers lies in access. These experiences are often expensive and can limit the audience who can participate. We can "no longer relegate global competency education to an add-on or luxury only for those who can afford it but instead must train all future teachers with this essential knowledge" (Witt, 2023, p. 300).

Slapac (2021) used a Global Teaching Model (GTM) to increase the global competency skills of grade 5-12 students in language classes. GTM uses authentic resources to investigate local-global issues (immigration, pollution) to go beyond the usual cultural connections of holidays and foods. Although students did reach their language goals, they were unable to approach global issues at a transformational level. A different approach was taken by Kopish (2017) to successfully teach global competencies that involved leveraging campus and community assets. The author notes that we are often "stuck within our own disciplinary borders and rarely seek or create opportunities to collaborate" (p. 44). Kopish attended events and networked with allies, partners, international students, and colleagues to develop a series of workshops. This led to impressive student reflections that showed the strength of cross-cultural experiential learning that depended on campus and community partnerships.

Research on Storybooks & STEM Education

Research on storybooks has demonstrated their effectiveness in fostering cultural literacy and understanding of diversity, particularly in early education. Storybooks have a way of holding attention, engaging readers visually, and emotionally connecting with readers, therefore, leading to an experience that is both intellectual and emotional (Ansberry, & Morgan, 2010; Yigit-Genten & Uyar, 2025). Specifically, having students engage in the creation of storybooks about their own culture has shown to lead to increased cultural competency and patriotism (Ursa, 2018; Wuryandani, 2020). This

approach has led to positive outcomes in multiple contexts; however, both studies focused solely on better understanding and having positive feelings about the dominant culture of their *own region*. Research conducted by Prasetya (2023) found similar results when using already published children's storybooks that focused on their own culture. Children showed an increased cultural diversity understanding of their own regional cultures.

Educating children at a young age about complex global STEM topics, like climate change, can help to foster awareness at an early age (Adam & Barratt-Pugh, 2020; Salmon et. al., 2024). Children can learn about the connected nature of preserving the planet in different cultures while learning about global competencies. Learning about climate change, a wicked problem, can often seem challenging and grim for young learners. The use of children's literature can create a playful learning setting where analysis of this issue is possible (Yigit-Genten & Uyar, 2025). Educators can foster a safe space for social and emotional learning while also posing critical questions that tap into STEM learning standards and cultural and geological characteristics explored in children's literature. Specifically, "children often identify with the main characters when stories capture their attention, thus opening scenarios to develop empathy" (p. 22). Adding the layer of selecting stories from different cultures allows for reduced othering by presenting relatable characters that are also different from us.

Focusing on the "M" in STEM education, similar research on global competencies and storybooks has also occurred in childhood mathematics classrooms. Harding et al. (2017) found that infusing multicultural mathematics storybooks placed cultural diversity in the forefront of preservice teachers' minds when they were planning mathematics lessons. Specifically, this approach led to purposeful integration of cultural diversity - making it an authentic part of the teaching cycle instead of an add-on piece. This research notes that it is crucial that educators ensure content learning goals are still achieved when attempting to integrate multicultural learning through storybooks.

Using diverse "storybooks as a medium for promoting global diversity among fourth-grade students demonstrated a significant impact on students' ability to recognize and appreciate different cultural identities" (Kuswendi et al., 2024, p. 91). However, selecting diverse children's storybooks to embed in STEM instruction is a challenging task. Grady (2019) completed a survey of children's storybooks and found that Asian and Latinx characters were often portrayed as being more emotional than characters of European descent. This presents our first challenge, many storybooks may represent different cultures in ways that can often generalize cultures and language backgrounds in stereotypical ways (Salmon et al., 2024). Given possible biases and misrepresentations, it is simply not enough to find a storybook that represents a culture. Educators need to consider how the choice of storybook could affect their students' perceptions of other cultures. The second challenge when selecting storybooks with diverse representation is an imbalance of STEM topics with accurate STEM information. Educators who are trying to find storybooks accurately representing all different STEM topics in their curriculum will already face a challenge. Attempting to find diverse cultural and geographical representation among characters in these books adds an even more taxing feat. To complicate matters further, Yoon (2022) found that even when diverse characters were present in these books, the storybooks rarely discussed how these characters were world citizens connected to other people around the world.

Collectively, these studies highlight the need for intentional, reflective, and justice-oriented approaches in teaching the knowledge, skills, and dispositions related to global competencies. As Witt (2023) reminds us, we "must radically reimagine the practice and possibilities of GCE for responding to the generation of students and teachers who know they live in a deeply connected, unjust world and need an immediate, coherent strategy for how to navigate and thrive in it" (p. 299). Yet missing from the existing literature is an empirically examined, replicable model for embedding global competency development directly within required elementary STEM methods courses. Specifically, a model that is accessible to all preservice teachers regardless of institutional resources or financial means. This study addresses that gap by demonstrating how intentionally curated diverse children's

storybooks, paired with inquiry-based instruction, can move preservice teachers beyond the surface-level cultural awareness that Thomas (2021) and Yoon (2022) identify as pervasive, toward the deeper pedagogical transformation and justice-oriented citizenship that the field demands.

Methods

Context Description

Researchers of this study included two professors who were instructors for the courses. The study included undergraduate elementary PSTs attending two institutions and were mostly from rural areas. SUNY Geneseo is a public college located in a rural area of the Northeastern United States with a student population that is 80% white, coming from mostly rural and suburban areas. Students in childhood certification programs enroll in a 4-credit STEM course, the course used for this study, where they learn about how to teach science and math to meet the needs of all learners. These students were sophomores or juniors near the beginning of their education course sequence. Indiana University Southeast is a public university with both undergraduate and graduate programs. This regional teaching focused campus is situated in the Midwestern United States. Students in the elementary and special education undergraduate programs take this methods course that also has a practicum tethered to it in their senior year. All students engaged in the ISE intervention as part of their course but had the ability to opt-in or opt-out of the data collection process anonymously.

The state contexts and undergraduate teacher preparation programs varied widely in terms of science education standards, the extent to which STEM integration was emphasized, the number of STEM methods courses required, the size of the teacher preparation program, and the geographic region.

We, the two authors and course instructors, held meetings online prior to implementation of the intervention to discuss features of the science methods course that served as the context of the study. During the meetings, we discussed curriculum needs and the philosophical and methodological approaches at our respective institutions. There were some differences in course topics however given the mission and vision the ISE was made an essential component of the course.

Description of Teaching Interventions

Positive experiences gained during science methods courses help support the self-efficacy of future science teachers (Palmer, 2006; Menon & Sadler, 2018). Teachers' science teaching beliefs influence their (a) instructional decisions (Rubie-Davies et al., 2012), (b) implementation of content in a classroom (Luft, 1999; Roehrig et al., 2007), and (c) reasons for engaging in certain types of science instructional practices, such as inquiry (Subramaniam et al., 2018). One way to promote the acquisition of information and new understandings is through the inquiry-based learning cycle model (Bybee, 2014). Additionally, we chose to implement the learning cycle inquiry-based model to "develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 1996, p. 23). This was an essential part for us since the intervention was based in a STEM methods course and layers onto the scientists highlighted in the intervention. Scientists and STEM professionals engage in complex tasks that include STEM process skills (See Table 1 below, Ponniers & Asim, 2016) and sense-making around the world. When preparing PSTs to teach science in PreK-12 schools, teacher educators embody the practices of STEM skills and model best practices for future teachers (Gess-Newsome, 2002).

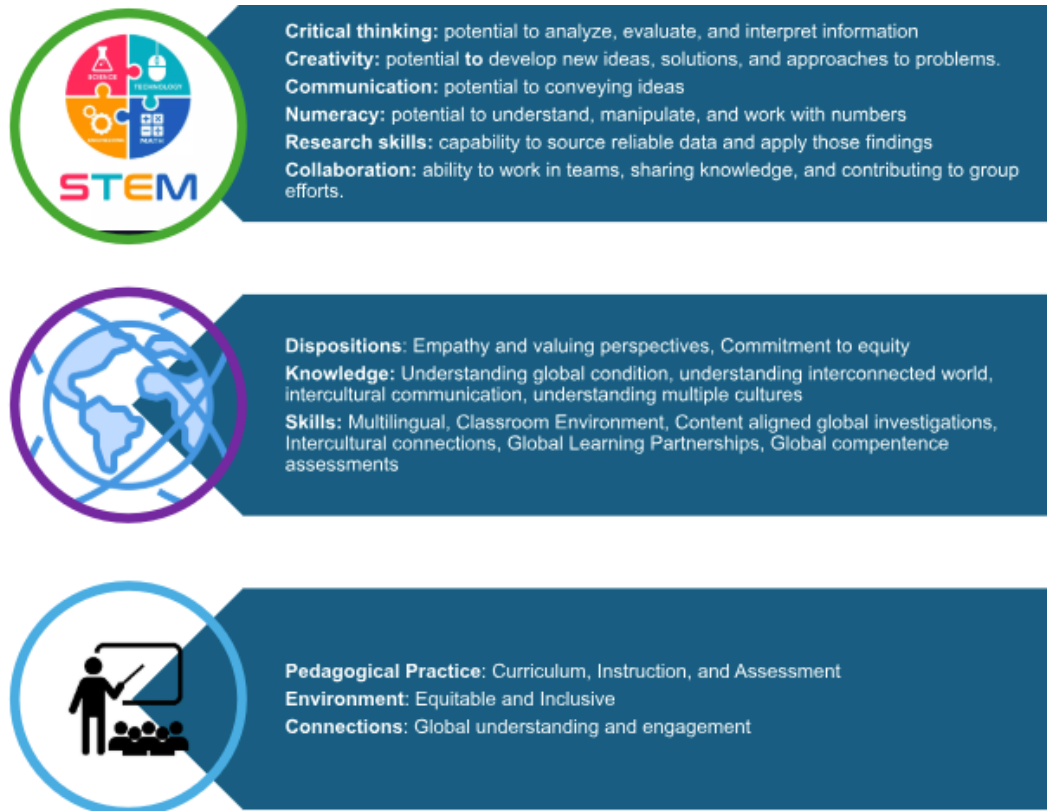
Table 1*STEM Process Skills Comparison Across Content Areas (Ponners & Asim, 2016)*

Science	Technology	Engineering	Mathematics
Observe	Define the problem	Identify the need	Problem Solving
Define the problem	Brainstorm	Define the problem	Mathematical communication
Infer	Research and generate ideas	Search for solution	Reasoning and Proof
Formulate Hypothesis	Identify criteria	Identify constraints	Communication
Predict	Specify constraint	Specify evaluation criteria	Connections
Measure	Explore possibilities	Generate alternate solutions	Representation
Control Variable	Select an approach	Engineer analysis	Appropriate Tools
Experiment	Develop a design proposal	Optimization	Precision
Analyze data	Build a prototype or model	Decision	
Evaluate hypothesis	Test and evaluate design	Design specification	
Communicate results	Refine the design	Communication	
Formulate theory	Make it and create it		
	Communicate results		

The methods courses at both institutions focused on supporting PSTs in developing knowledge, skills, and dispositions in global competencies along with research-based science instructional practices. Carefully chosen fiction and nonfiction books can allow students to practice their critical thinking and comprehension skills while providing science content knowledge (Mahzoon-Hagheghi et al., 2018; McGinnis, 2020). Elementary school teachers use books almost every day in their classroom (Sackes et al., 2009). Therefore, using children's literature to engage students in thinking about countries and people across the globe (Yoon, 2022) seemed like an accessible and

synergistic tool. Many science educators may refer to and try the National Science Teaching Association's (NSTA) Outstanding Science Trade Books for Students K-12 listing, which was an inspiration for us, and we believe that a curated book list with a global focus may be useful for teacher preparation programs as well as K12 educators. Like NSTA's Picture Perfect curriculum guides, the storybooks help engage students in learning STEM content. The selected storybooks helped generate conversations related to various cultures, practices, processes, vernacular, and resources. Connecting elementary classrooms to different geographical locations and cultures can also help build a foundation for empathy and embracing differences.

PSTs were engaged in modeled inquiry-based STEM lessons that integrated storybooks with diverse ethnic, cultural, linguistic, or ability diverse representation. These books served as a vehicle for exploring science concepts while simultaneously broadening the PSTs' understanding of global STEM education. Each lesson was carefully designed to align with the United Nations Sustainable Development Goals (UNSDG), encouraging PSTs to consider values, beliefs, resources, and practices from different cultural contexts. Common model lessons anchored by storybooks and assignments were implemented in both universities. The courses included concurrent participation in a practicum, allowing PSTs firsthand observation and interaction with elementary students. Our intervention, named the internationalization of science education (ISE), includes three elements: 1) inquiry-based model STEM lessons, 2) a children's book that highlights a different region of the world, and 3) engaging learners in meaningful discussions of culture to build awareness and empathy (see Figure 1). The inquiry-based-model STEM lesson helps to build the process skills mentioned in Table 1 and overlaps with the development of 21st Century Skills. 21st Century skills include creativity, critical thinking, communication, collaboration, digital literacy, problem solving and productivity (Voogt, et al., 2013). While the focus of this study centers on global competencies, 21st Century Skills and global competency frameworks share significant overlaps, particularly the shared emphasis on critical thinking, communication, and collaboration. Developing 21st Century Skills through inquiry-based STEM instruction provides a complementary foundation upon which global competency dispositions, such as cross-cultural communication and collective problem-solving, can be built.

Figure 1*Internationalization of Science Education Intervention*

Note. The ISE intervention integrates three interconnected domains: STEM (creativity, communication, numeracy, research skills, and collaboration), global competency (dispositions, knowledge, and skills from the GCTC framework), and pedagogical practice (equitable curriculum, instruction, assessment, and global engagement).

We, as teacher educators, wanted to use books to engage students in a broader connection of science content and expand the perspectives of our PSTs. Regions of the globe such as the Middle East and Asia were purposefully on our radar as we collected a selection of books for this study (Table 2).

Table 2*Inquiry-based STEM Lessons with Aligned Diverse Storybooks*

<i>Inquiry-Based Science Lesson</i>	<i>Children's Storybook with Diverse Representation</i>	<i>Country Represented</i>
Building Up (Ansberry & Morgan, 2023)	The World is not a Rectangle: A Portrait of Architect Zaha Hadid by Jeanette Winter (2017)	Iraq
Let's Drum (Ansberry & Morgan, 2022)	Drum Dream Girl: How One Girl's Courage Changed Music by Margarita Engle (2015)	Cuba
Glo-Germ Lab (Educational Innovations, 2015)	Tu Youyou's Discovery: Finding a Cure for Malaria by Songju Ma Daemickle (2021)	China
Pollution in the Well Lab (Seneca Park Zoo, 2016)	Saving Salila's Turtle: An Environmental Engineering Story by Martin, J., & Boston Museum of Science (2006)	India

Data Collection

The study included enrolled PSTs in an elementary science or STEM methods course that incorporated the ISE intervention. All PSTs engaged in the ISE intervention as part of their coursework, however participation in the research component was voluntary. Only responses from the PSTs who consented to research use were included in the final analysis. No other exclusion criteria were applied. Data was collected across two semesters in 2024. Data was collected at the beginning and end of the semester to determine the ways in which our interventions impacted our preservice teachers. SUNY Geneseo had 84 students participating in four class sections, and there were 27 students from Indiana University Southeast in two class sections.

Quantitative Survey Instrumentation

A 5-item Global Learning Survey was used to assess changes in preservice teachers' global perspectives before and after an instructional intervention in a science methods course within education preparation programs. The instrument was introduced to the second author through participation in the professional learning community for teacher educators from multiple institutions during 2022-2023 Globalizing Rural Science Teacher Education. The survey was shared by one of the facilitators and was originally adapted from the Global Competence Matrix developed by the Asia Society, EdSteps, and the Council of Chief State School Officers (CCSSO) (Dimitrieska, 2017). ACE's (2018) Comprehensive Internationalization Framework provides clear definitions of *globalization* (i.e., movement of ideas, people, good, services across the globe; uncontrollable by individual people) and *internationalization* (the higher ed institutions' response to globalization by intentionally incorporating global content, global perspectives, etc. in their programs, lessons, and teaching). Results from the pre- and post-surveys were analyzed to determine shifts in participants' perceived global competence following the intervention.

The Global Learning Survey tool was ultimately selected over more rigorous tools, such as the GCTC, in order to increase student response rates. Similarly, survey data was also gathered

anonymously and not viewed until after the closing of the semester to appease any student concerns about the results or their choice to opt-in or opt-out of study affecting their course grade.

Our survey included the following questions with a four-point Likert scale:

1. I can communicate and collaborate across national and cultural boundaries.
2. I can make choices and design solutions informed by multiple frames of reference including international, global, and cultural contexts.
3. I can demonstrate openness, recognition, and acceptance of differences.
4. I can demonstrate willingness to adapt my own practices, values, and behaviors.
5. I am willing to act upon acquired knowledge, skills, and attitudes in global and local contexts.

Qualitative Survey Instrumentation

In addition to Likert-scale questions, written reflections were also solicited. The following questions were asked at the beginning and close of the semester:

1. How can you demonstrate openness, recognition, and acceptance of diverse populations in your future classroom?
2. What skills do you have to communicate and collaborate across national and cultural boundaries?
3. What choices and instructional design ideas do you have to address international, global, and cultural contexts?

Mixed Methods Approach

Following the mixed-methods principle, the two methods we used measured the same concept (Creswell, 2014). While the qualitative and quantitative data were collected simultaneously at the same two timepoints — pre- and post-survey — and analyzed separately using appropriate analytic techniques, the interpretation phase employed a convergent mixed-methods approach (Creswell & Plano-Clark, 2018).

Data Analysis

Quantitative Analysis

To measure the impact of the ISE intervention, PSTs participated in pre- and post-surveys, utilizing a combination of quantitative and qualitative measures to evaluate their global competencies. Data were collected in Spring 2024 and Fall 2024 semesters. These assessments focused on the educators' ability to incorporate global competency skills into their teaching strategies and their evolving understanding of the importance of preparing young students for a globally interconnected world. Quantitative data was analyzed independently using a 2-tailed independent samples t-test (Privitera, 2024) because we had no identifiers to pair pre- and post- assessments among the anonymously collected data.

Qualitative Analysis

Each of us independently coded the participant reflection responses. Following this process, we met to identify discrepancies and reach a consensus on code development, ensuring consistent interpretation of participant responses (Creswell & Plano Clark, 2018). A second round of coding resulted in refinement of the codes through a constant comparative method (Clandinin & Rosiek, 2007). We also reflected on preliminary codes that were associated with global competency skills, knowledge, and dispositions. We then conducted a thematic analysis (Saldana, 2021) collaboratively. Initial themes were identified and codes were compared across all qualitative data sources to identify patterns and contradictions. At the conclusion of this process six major themes were identified without reference to the quantitative findings, preserving the independence of each analytical strand.

Data Triangulation

Once quantitative and qualitative data were analyzed independently in the same phase of research, they were compared with a goal of assessing whether the datasets contained similar or diverging findings (Creswell & Plano-Clark, 2018). We collaborated throughout this process to increase interrater reliability of the connections identified. Themes from the written reflection responses were compared with the patterns in the survey results to triangulate findings and to better understand how PSTs experienced changes in their dispositions and instructional practice. Convergence across strands was substantial, with Themes 1 and 6 aligning with significant growth in Q4 and Q5, Themes 3 and 5 with Q1, and Themes 2 and 4 with Q2. The one area of divergence — Q3's ceiling effect — was clarified by qualitative data showing PSTs already held strong dispositional openness but lacked the skills to enact it, illustrating the added explanatory value of the concurrent design.

Results

The findings indicate that the iterative nature of the ISE intervention was well received, with quantitative and qualitative data analysis revealing student growth regarding several variables. Both course professors also noted during informal observations that their students were highly engaged in the ISE lessons and embraced many of the newly introduced children's storybooks with diverse representation.

Quantitative analysis revealed significant changes for four of the five questions posed to participants. Data showed growth in their self-analysis of global competency skills in each of these four categories (see Table 3). Question 3 was the only prompt that did not have a significant p value, but it did have a very high self-assessment rate on the post-assessment. Due to Question 3 also having the highest self-analysis on the pre-assessment (3.764) it did not lead to a significant finding when compared to the post-assessment scores.

Table 3*Pre- & Post- Quantitative Data Summary*

Question	N _{pre}	M _{pre}	SD _{pre}	N _{post}	M _{post}	SD _{pos} t	p
1. I can communicate and collaborate across national and cultural boundaries.	111	2.955	0.477	108	3.178	0.563	0.002
2. I can make choices and design solutions informed by multiple frames of reference including international, global, and cultural contexts.	111	2.790	0.560	108	3.206	0.562	< 0.001
3. I can demonstrate openness, recognition, and acceptance of differences.	111	3.764	0.448	108	3.748	0.551	0.815
4. I can demonstrate willingness to adapt my own practices, values, and behaviors.	111	3.563	0.498	108	3.710	0.567	0.044
5. I am willing to act upon acquired knowledge, skills, and attitudes in global and local contexts.	109	3.398	0.546	108	3.598	0.597	0.011

Qualitative Themes

Qualitative analysis of pre- and post-survey responses revealed variation in themes among student data (summarized in Table 4). Both the pre- and post-survey responses led to the identification of six major themes. Although these themes are categorically similar, such as classroom environments being the first theme for both, the nuances in student language choice help us see a shift in their thinking.

Table 4

Qualitative Themes for Pre- vs. Post Data

Pre-Survey Qualitative Themes		Post-Survey Qualitative Themes
1 Classroom Environment	Cultural Inclusion Through Classroom Environment Visual Cultural Representation, Creating Welcoming Spaces, Fostering Acceptance and Belonging, Building Relationships	Creating Safe and Welcoming Environments Establishing Welcoming Spaces, Ensuring Psychological Safety, Promoting Open Expression
2 Teaching Materials with Diverse Representation	Diverse Representation in Curriculum Diverse Learning Materials, Inclusive Character Representation, Cultural Content Integration, Expanding Diversity Resources	Diverse and Inclusive Learning Materials Diverse Book Collections, Representational Materials, Inclusive Resource Variety
3 Supporting Linguistic and Cultural Diversity	Language Accommodation & Communication Language Support, Translation Tools, Multilingual Abilities, Non- verbal Communication	Culturally Responsive Teaching Approaches Culturally Responsive Pedagogy, Cultural Knowledge Integration, Equitable Teaching Practices, Adaptive Teaching
4 Specific Cultural Teaching Approaches	Active Cultural Learning Strategies Cultural Holiday Exploration, Student Recognition, Cultural Education Approaches, Cultural Curriculum Development	Cultural Representation and Celebration Cultural Visibility, Student Recognition, Cultural Celebration, Cultural Awareness and Sharing
5 Students Discussing Cultures	Student-Centered Cultural Exchange Student Voice and Sharing, Facilitated Cultural Dialogue, Community Building	Communication Across Boundaries Multilingual Communication, Translation Resources, Family Engagement, Collaborative Communication
6 Teacher Growth Regarding Cultures	Personal Cultural Awareness & Growth Bias Recognition, Professional Development, Cultural Curiosity and Openness, Active Cultural Learning	Teacher Growth and Self- Education Professional Modeling, Open- mindedness, Active Listening and Learning, Cultural Understanding

Categories with the largest shifts in language use appear to be Category 1: Classroom Environments, Category 3: Supporting Linguistic and Cultural Diversity, Category 4: Specific Cultural

Learning Approaches, Category 5: Discussion Cultures, Category 6: Teacher Growth Regarding Cultures. Student word choice in each of these categories became more specific, citing teaching practice and specific examples, instead of generalized approaches or surface-level concepts. Category 2: Teaching Materials with Diverse Representation does not show a major difference among codes.

Findings for Research Question a: Global Competencies

Student Self-Assessment of Global Competency Skills. The survey functioned as a metacognitive tool contributing to improvements as seen in the results obtained in Table 3. Student quantitative data shows significant growth regarding student self-analysis of their global competency skills.

Question 3 showed high scores in both pre- and post-surveys, but no significant findings (no major shift in data). PSTs entered with strong dispositions toward openness (3.764/4.0) but they lacked the skills and knowledge to enact this disposition—which the intervention then developed (as shown in Q1, Q2, Q4, Q5). This pattern is consistent with the GCTC framework's distinction between dispositions (which many PSTs already held) and the knowledge and skills required to act on those dispositions (Longview Foundation & Learn NC, 2014).

Pedagogical Transformation. PSTs demonstrated a clear progression from surface-level understanding to intentional pedagogical integration. Pre-survey responses reflected limited conceptions often framed as "cultural holiday exploration" and visual classroom decorations. In contrast, post-survey responses demonstrated a more sophisticated understanding, with PSTs articulating approaches grounded in "culturally responsive pedagogy" and intentional instructional design that embedded cultural perspectives throughout their teaching practice.

This shift signifies a deeper understanding between culture and content instruction. One PST reflected: "When I was writing my lesson plan and teaching my STEM lesson I learned to value cultures other than my own. I knew students would finish building their tent a lot earlier than some of the other students, so I printed off coloring pages. I thought about where some of my students were from in my classroom. One of the coloring pages showed the sun in Mexico, and the other ones had the sun by the ocean, and one was in the mountains" (Indiana University, Fall, Post-Survey). This response illustrates movement beyond superficial representation to authentic integration of cultural context in science content.

The inquiry-based pedagogy in the ISE catalyzed global competency development. By engaging PSTs in active questioning, investigations, and meaning-making around STEM phenomena embedded within culturally diverse contexts, the inquiry-based lessons created natural opportunities for examining how scientific practices and knowledge are influenced by cultural perspectives and resources. This pedagogical integration addresses concerns raised by Harding et al. (2017) about maintaining content learning goals with multicultural perspectives—our findings suggest that embedding cultural contexts within inquiry-based STEM lessons enhances both content mastery and cultural awareness.

Storybooks served as authentic contexts for STEM learning that naturally incorporated cultural perspectives, values, and practices. For instance, using Tu Youyou's *Discovery: Finding the Cure for Malaria* not only introduced PSTs to scientific inquiry but also highlighted how cultural contexts shape scientific work. This approach aligned well with Kuswendi et al. (2024) and addressed the challenge identified by Yoon (2022) that many diverse storybooks fail to discuss global citizenship and interconnectedness.

Post-survey responses show PSTs articulating specific instructional strategies, such as: "My ideas to address these topics in my classroom include selecting culturally relevant content, materials

and resources. I will also include global perspectives like current events, global challenges, etc." (Indiana University, Spring 2024, Post-Survey). This move toward specific strategies, rather than vague comments on inclusivity, indicate that the ISE intervention successfully developed not just dispositions but also pedagogical knowledge and skills necessary to enact culturally responsive STEM instruction.

Lifelong Learning Orientations. Qualitative data revealed a significant shift in how PSTs conceptualized their relationship to cultural knowledge and global competency development. Pre-survey responses frequently included phrases like "I would need to research more" or "I need to learn about," positioning PSTs as passive recipients awaiting cultural information. Post-survey responses demonstrated a fundamental transformation in teacher identity, with PSTs using language such as "open-minded," "active listening," and "engaging in life-long learning" to describe their ongoing commitment to understanding diverse cultures and meeting learners' needs.

The conceptual shift represents more than acquiring new knowledge—it reflects a reconceptualization of global competency as an evolving professional responsibility rather than a finite skill set. One PST articulated this transformed perspective: "My ideas to address these topics in my classroom include selecting culturally relevant content, materials and resources. I will also include global perspectives like current events, global challenges, etc. I will also make sure I am always educating myself" (UN2 SPG 24 POST, GC). The phrase "I will also make sure I am always educating myself" signals a commitment to continuous learning that extends beyond the methods course.

This conceptual shift toward lifelong learning orientations also appeared in PSTs' recognition of students themselves as cultural knowledge sources. Post-survey responses increasingly referenced "letting students teach us as well" (UN2 SPG 24 POST, KS), positioning learners as co-constructors of cultural understanding rather than passive recipients.

Research Question b: Future Classroom Environment Design

Classroom Environment. One of the most significant transformations revealed among our qualitative data was the shift in PSTs' language about classroom environments. Pre-survey responses emphasized surface-level accommodations, such as visual representations, welcoming decor, and general acceptance. Post-survey responses demonstrated a much deeper understanding of creating safe spaces that promote student expression and agency.

Examples of pre-survey reflections:

- A. "[e]xposing students to manageable amounts of foreign language vocabulary" (SUNY Geneseo, Pre-Survey, Fall 2024),
- B. "[e]xpanding on my DEI materials such as posters, books, toys/classroom materials. Also, make it a point to make a statement to my students on acceptance and how hate won't be accepted" (SUNY Geneseo, Pre-Survey, Fall 2024), and
- C. "you can use read-alouds that respect not only the diverse population in your classroom but also in the world. Treating anyone like a human and human experiences goes a long way. Having diverse classroom decor and guests can cultivate a learning environment that welcomes differences and diversity" (Indiana University, Pre-Survey, Spring 2024).

In contrast, a post reflection stated:

I always try to get to know my students on a personal level to better understand their background and culture. I talk to my students in the morning, at recess, when waiting for dismissal, and at odd times throughout the day. I also try to be flexible when it comes to

how a student does an activity. If they want to be more hands-on, only writing, or speaking, it is up to them. I also try to make what I am teaching connected to real world situations or problems. Having students learn about the world around them can make them more culturally aware too (Indiana University, Post-Survey, Fall 2024).

Responses illustrate a shift in our teachers' understanding of a classroom environment from a static, decorated space to a dynamic, socially-mediated learning community. The ISE intervention placed an emphasis on discussing many of these topics with students following model lessons, which may have aided our PSTs in making their view of the classroom environment inseparable from student relationships and pedagogical choices. This aligns well with our own observations as professors and researchers, as we saw our students evolve as they brought substantially more depth to creating classroom communities, with many of their responses overlapping heavily with Theme 6: Teacher Growth Regarding Cultures.

Research Question c: Instructional Design Choices

Family and Community Engagement. By the end of the semester, PSTs' reflections increasingly emphasized the importance of family and community engagement. In Table 4, Category 4: Specific Cultural Teaching Approaches and Category 5: Students Discussing Cultures show the appearance of new approaches to engaging families and celebrating cultures that were not considered among the pre-survey data. PSTs used terms such as "family engagement," "cultural collaboration," and "multilingual communication," whereas at the start of semester they used terms like "student voice" and "facilitated cultural dialogue."

This shift represents a reconceptualization of the classroom as a broader community ecosystem rather than an isolated instructional space. Post-survey responses demonstrated PSTs had developed an expanded understanding that authentic cultural learning requires connecting with families and communities beyond the school building. This aligns with research on culturally responsive pedagogies which emphasize the importance of building bridges between school and home cultures (Gay, 2000). One PST articulated this expanded perspective:

First I would describe the meaning of family and how family looks different for all of us. Having posters of leaders of every kind hanging around the room, because we need to see, not just hear about diversity. Music is important for everyone (Indiana University, Post-Survey, Spring 2024).

The appearance of "multilingual communication" in post-survey responses suggests PSTs moved beyond viewing language diversity as a barrier to overcome and instead began seeing it as an asset to embrace. One PST specifically noted:

They loved the coloring pages and got to finish them later that day. Then for one of my extensions activities I linked a website that had a science game that was all about the sun. On this website you can switch the languages. I thought this was very helpful because half of my class was ELL students, so I knew this would be beneficial for them, and they would understand because the instructions were read to them in their language (Indiana University, Post Survey, Fall 2024).

This example demonstrates proactive efforts to use multilingual tools for equitable engagement, signaling a move from accommodation to integration of family-engaged pedagogy. The qualitative data also revealed PSTs increasingly considered how cultural celebrations could extend beyond the classroom to include family participation, representing a significant development in global competency understanding consistent with Thomas's (2021) justice-oriented approach to diversity.

Specific Cultural Teaching Approaches. PSTs increasingly discussed designing learning experiences that focused on cultures represented in their classrooms. Post-survey responses revealed intentional strategies from general cultural awareness to systematic instructional planning. One PST noted:

Choices and instructional ideas I have to address [international], global and cultural context include incorporating diverse perspectives in the curriculum I teach, global awareness projects, representing diverse cultures in my classroom, having guest speakers and even show-n-tell where students share about their background (Indiana University, Post-Survey, Spring 2024).

This movement demonstrates how the ISE scaffolded PSTs' understanding of culturally responsive STEM instruction as a fundamental lens through which all instructional decisions should be filtered. Another PST reflected:

Even now, I'm still studying the Korean culture as it will be the culture I'm immersed into in a year or so. I truly do believe that when you're creating lesson plans or activities, that you are aware of your students' cultures, especially if they are not born and raised here in the US. You never want your students to feel left out due to not implementing things about their culture that they miss (Indiana University, Post-Survey, Fall 2024).

This response highlights the personal investment PSTs developed in understanding their students' cultural contexts and surfaces a productive tension inherent in global competency work: while the ISE intervention was designed to broaden PSTs' perspectives outward toward global interconnectedness, moments like this illustrate how that orientation simultaneously drew PSTs inward toward the specific local and cultural identities of their own students. This duality is consistent with the PISA framework's vision of global competence as encompassing both issues of local and global significance (Boix-Mansilla & Schleicher, 2022), and with Slapac's (2021) finding that meaningful global competency development depends on connecting local realities to broader global issues.

The intentionality expressed by PSTs in their post-surveys marks a critical shift from reactive to proactive cultural integration. Pre-survey responses often positioned culture as something to respond to when diverse students were present. Post-survey responses revealed PSTs planning for cultural diversity as a default assumption, recognizing that even seemingly homogeneous classrooms benefit from global perspectives (Byker, 2018). The alignment with UN Sustainable Development Goals provided PSTs with a practical curricular organizing framework that elevated cultural teaching approaches beyond surface-level celebrations, making cultural diversity integral to STEM learning objectives rather than separate from them.

Discussion

The ISE methods course intervention created opportunities where PSTs were able to encounter not only new perspectives but also engage with tools, tasks, and academic terminology to articulate their identities as a STEM educator and global citizen. Global competence encompasses knowledge, skills, and dispositions. Through ISE, PSTs strengthened their global competencies, fostering career readiness and collective responsibility as global citizens.

The Role of Diverse Storybooks as an Accessible Tool

The ISE intervention's reliance on diverse storybooks as the primary vehicle for global competency development addresses a critical equity challenge in teacher preparation. While study abroad programs have demonstrated exceptional strength in developing global competency skills among preservice teachers (Byker, 2018), yet these experiences remain inaccessible to many students

due to cost, time constraints, family obligations, and other barriers. Our study demonstrates that carefully selected storybooks paired with inquiry-based STEM instruction can provide an accessible, cost-effective alternative within required methods courses.

Storybooks offer several advantages for democratizing access to global competency development. First, storybooks are already familiar pedagogical tools that elementary teachers use regularly in their classrooms. PSTs expanded their existing literacy practices to encompass global dimensions, likely contributing to the high engagement levels observed. Second, diverse storybooks provide windows in dimensions, and contexts that might otherwise remain abstract. The narratives demonstrated how scientific knowledge is culturally situated and how different communities approach shared global challenges using varied resources, values, and knowledge systems. Third, this approach is adaptable across institutional contexts. Our study included PSTs from two different locations with varying course structures, geographic locations, and student populations, yet both successfully implemented the ISE intervention using the same curated storybooks. The curated list of recent storybooks in Table 5 offers other teacher educators a ready-to-use resource for incorporating global perspectives into STEM methods courses without requiring extensive curriculum redesign, specialized training, or additional funding. This accessibility is very different from study abroad programs, which require substantial institutional infrastructure, partnerships, and financial investment.

However, storybooks alone are not sufficient enough for developing global competencies—the pedagogical approach matters significantly. Our pairing of storybooks with inquiry-based instruction and facilitating classroom discussions about culture and global interconnectedness also played a large role.

Implications for STEM Methods Courses and Teacher Preparation

This study makes several specific contributions to the existing literature on global competency development in teacher preparation. Most directly, it provides an empirically examined, replicable model for embedding global competency development within required elementary STEM methods courses, which is a gap that Thomas (2021) and Witt (2023) explicitly identified as needing to be filled. Where prior efforts have addressed global competencies either as standalone diversity courses, costly study abroad experiences (Byker, 2018), or surface-level cultural add-ons (Thomas, 2021; Yoon, 2022), this study demonstrates a viable, low-cost, institutionally accessible alternative that produced measurable growth in PST dispositions, knowledge, and skills. In doing so, it directly answers Witt's (2023) call to stop relegating global competency education to a "luxury only for those who can afford it" and instead train all future teachers with this knowledge as a standard component of their professional preparation.

A second contribution lies in demonstrating that rigorous STEM content learning and global competency development are not competing priorities. Harding et al. (2017) flagged a critical concern that integrating multicultural perspectives through storybooks risks subordinating content learning goals. Our findings challenge this framing: PSTs showed growth both in their articulation of inquiry-based STEM instructional strategies and in their global competency dispositions and skills, suggesting that the two reinforce rather than undermine each other when pedagogical integration is intentional. This is consistent with Ansberry and Morgan's (2010) argument that children's literature can anchor rigorous science inquiry and extends that argument by demonstrating the same is true when the books carry explicit global and cultural dimensions.

A third contribution addresses a specific critique raised by Yoon (2022), who found that even when diverse characters appeared in children's storybooks, those books rarely positioned characters as world citizens connected to broader global systems. Our curated selection and inquiry-based pedagogical framing were designed precisely to counteract this tendency by pairing each book with deliberate discussion of global interconnectedness and alignment with the UN Sustainable

Development Goals (United Nations, 2018; UNESCO, 2015). The qualitative data showing PSTs' post-survey language shifting from "cultural holiday exploration" toward "global awareness projects" and "interconnected global challenges" suggests this pairing was effective at moving beyond the kind of surface-level cultural representation Yoon (2022) critiqued.

These contributions have several implications for how STEM methods courses are designed. First, the inquiry-based approach appears essential for connecting cultural learning to disciplinary practices. The GCTC framework (Longview Foundation & Learn NC, 2014) identifies inquiry as a core teacher skill for global competency. Specifically, developing and using methods of inquiry to assess students' global competence, and our findings suggest that modeling this approach in methods courses creates natural opportunities for PSTs to experience it from the learner's perspective before enacting it in their own classrooms. Methods courses that primarily emphasize direct instruction or procedural teaching skills may miss these opportunities.

Second, the deliberate selection and integration of diverse children's storybooks provide an accessible entry point for methods course redesign. The socioemotional power of narrative, the way stories open readers to empathy by allowing identification with characters unlike themselves (Yigit-Genten & Uyar, 2025), appears to operate effectively for adult PSTs as well as for the elementary students they will eventually teach. Methods instructors could begin by replacing one or two existing lessons with storybook-anchored investigations like those described in Table 2, gradually expanding as they develop confidence facilitating cultural discussions alongside STEM content. Critically, unlike the GTM approach used by Slapac (2021), which also drew on authentic resources to investigate global issues but was unable to move students to a transformational level, our pairing of storybooks with structured inquiry and reflection appeared to support deeper dispositional change. This likely occurred because it was embedded within the professional identity-forming context of a methods course rather than a language class.

Third, our findings highlight the importance of explicitly naming and discussing global competencies throughout methods courses, rather than assuming these dispositions will develop organically. The self-assessment surveys functioned as metacognitive tools that prompted PSTs to articulate their developing competencies in terms aligned with the GCTC's Dispositions, Knowledge, and Skills categories (Longview Foundation & Learn NC, 2014), likely contributing to the growth we document. Methods courses should incorporate structured reflection opportunities where PSTs consider how their instructional choices connect to culturally responsive STEM teaching (Gay, 2000) and global citizenship development (UNESCO, 2015).

Fourth, this study reinforces that global competency development requires sustained, integrated engagement rather than isolated experiences. Kopish (2017) demonstrated the power of cross-cultural experiential learning sustained across a semester through campus and community partnerships; our findings suggest that a parallel kind of sustained engagement built not through external partnerships but through the iterative layering of storybooks, inquiry, discussion, and reflection across a full semester can produce comparable dispositional growth within the more accessible context of a single required course. Teacher preparation programs should consider how global competency learning can function as a continuous thread woven through the entire preparation sequence, rather than a unit confined to one course.

Finally, our findings point to the value of aligning STEM instruction with the UN Sustainable Development Goals as an explicit organizing framework. The SDGs helped surface how different cultures approach shared global challenges using varied resources, values, and knowledge systems, which makes cultural diversity integral to STEM learning rather than supplementary to it. However, our particular implementation did not yet make the SDG framework fully visible to PSTs as a planning tool. A future iteration in which PSTs explicitly use the SDGs to design their own lessons would likely deepen both global competency development and the transferability of that learning to their own practice.

Limitations

We acknowledge that our study has some limitations as to its transferability. It was conducted in two rural contexts with relatively small class sizes (12-25 PSTs). The implementation approaches of the ISE intervention and data collection also slightly varied slightly between our two courses. One of us taught a 4-credit STEM methods course (including math and science instruction) with field-based teaching, and the other taught a 3-credit science-specific methods course. This shift in course design led to students experiencing some additional math-specific ISE intervention experiences in the 4-credit course, and students also then taught a model lesson in the field using a storybook with diverse representation. Regarding data collection, at SUNY Geneseo, students participated in only the pre- and post-assessment and the conversations regarding global competencies that occurred during the ISE intervention. However, at Indiana University Southeast, students regularly engaged in reflections using a journaling approach. This journaling approach led to much more robust responses to our qualitative questions in the post-survey.

Students also grew and were influenced by factors outside of the ISE intervention. During this four-month window, students carried a full semester schedule of additional courses and their own lived experiences. These lived experiences outside of the science/STEM methods courses may have contributed to any shift in the PSTs' global competencies.

Future Work

We concur with and borrow related terminology and categories from the review of literature that state that PSTs need to develop instructional practices that will meet the needs of being a global citizen. We are in no way pioneering the concept of global competencies; however, we believe that transformative practices such as the ISE and methods courses can increase the quality of science & STEM instruction. Throughout the process of this research project, we strove to advance the understanding about preparing students to have conversation between inquiry-based teaching and emphasizing the development of professional dispositions that integrated a global lens. Reflection is a powerful tool to allow PSTs to reflect on their own teaching beliefs, skills and dispositions. Our attempt at designing the interventions was overtly to provide a space to explore ways to better align instruction to the needs of being a global citizen and scaffold global competencies. Teacher education preparation programs, and the teacher educators, have a responsibility to prepare PSTs with several sets of skills that will help them in their future classrooms to meet the needs of various backgrounds and cultures. Being cognizant of teachable moments and showing awareness of different teaching approaches, assessment strategies, classroom management, classroom learning environments and science/STEM content knowledge must be part of science & STEM methods courses. Science methods courses need to gain experiences with addressing broader cultures. When PSTs read aloud storybooks they invite student listeners to engage with culture and STEM content; therefore, allowing them to stimulate scientifically literate discussions. Since choosing appropriate storybooks to teach STEM content is not a simple task, we have curated a longer list of storybooks from the past six years to share that we believe would be helpful for other methods instructors (Table 5). This study has indicated that books are not just tools for teaching rather they allow readers to construct their own dispositions about the surrounding world.

Table 5

Curated Global Storybooks List for Elementary STEM Courses

Book Title	Author(s)	Geographic Location or Cultural Focus
Tu Youyou's Discovery: Finding a Cure for Malaria (2021)	Songju Ma Daemicke	China
Save Our Forest (2024)	Nora Dåsnes	Norway
Forest Fighter: The Story of Chico Mendes (2022)	Anita Ganeri	Brazil
Secrets of the Sea: The Story of Jeanne Power, Revolutionary Marine Scientist (2021)	Evan Griffith	Italy
Santiago Saw Things Differently: Santiago Ramón y Cajal, Artist, Doctor, Father of Neuroscience (2023)	Christine Iverson	Spain
Autumn Peltier, Water Warrior (2023)	Carole Lindstrom	Indigenous Communities in Ontario, Canada
Flipflop!: How a Boat Made from Flip-Flops is Helping to Save the Ocean (2023)	Linda Ravin Lodding and Dipesh Pabari	Kenya
Dinosaur Lady: The Daring Discoveries of Mary Anning, the First Paleontologist (2020)	Linda Skeers	England
Building Zaha: The Story of Architect Zaha Hadid (2020)	Victoria Tentler-Krylov	Iraq
Fly, Girl, Fly (2020)	Nancy Roe Pimm	Refugee from Afghanistan
June Almeida, Virus Detective (2021)	Suzanne Slade	Scotland
Mother of Sharks (2023)	Melissa Cristina Márquez and Devin Elle Jurtz	Puerto Rico
Beatrix Potter, Scientist (2020)	Lindsay Metcalf	Scotland

The Tree of Hope (2022)	Anna Orenstein-Cardona and Juan Manuel Moreno	Puerto Rico
River of Mariposas (2023)	Michelle Ortega	Mexico
When the Ocean Came to Town (2023)	Sal Sawler	Canada
The Forest Keeper: The True Story of Jadav Payeng (2023)	Rina Singh	India
Sona Sharma, Looking After Planet Earth (2024)	Chitra Soundar	India
Rats to the Rescue (2024)	Scott Riley and Sambat Meas	Cambodia
Ganesha Goes Green (2023)	Lakshmi Thamizhmani	India
When the Storks Came Home (2022)	Isabella Tree	United Kingdom
Joan Procter, Dragon Doctor: The Woman Who Loved Reptiles (2023)	Patricia Valdez	England
Eco Girl (2023)	Ken Wilson-Max	Africa
Up, Up, Ever Up! Junko Tabei: A Life in the Mountains (2024)	Anita Yasuda	Nepal

Overall, this study provides additional evidence that we need to further strengthen teacher preparation by using strategies that can make meaning, connect science practices, and with intentionality help our future elementary teachers develop as globally competent educators. We as science educators are aware that science/STEM instruction is not a priority in many of our partnering elementary schools as strategically using literacy block with children's books has great potential. The ISE intervention demonstrates that global competency development need not compete with rigorous STEM content learning—rather, when thoughtfully integrated, these goals can reinforce one another. As our world grows increasingly interconnected and our classrooms more diverse, preparing teachers who can navigate cultural boundaries, design culturally informed instruction, and foster global citizenship becomes essential rather than optional. The shifts we document—from surface-level awareness to pedagogical integration, from reactive accommodation to proactive planning, from passive learning to lifelong inquiry—suggest that methods courses can serve as powerful sites for dispositional transformation when we deliberately design them with this purpose. If we are to prepare teachers capable of educating the next generation of global citizens, we must ensure that global competencies are found throughout our teacher education preparation programs rather than treated as enrichment.

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

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Exploring Epistemological Beliefs and Network Associations of STEM Faculty

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ABSTRACT

Interactions among faculty members play a critical role in the diffusion of research-based instructional strategies (RBIS). Prior research suggests that non-tenure-track faculty differ significantly from their tenured counterparts in teaching practices and engagement with instructional reform. This study explores how faculty members' teaching-related epistemological beliefs influence their engagement with RBIS and their relationships in collegial networks. Using an interpretive phenomenological approach, we analyzed faculty narratives to capture their beliefs about teaching and RBIS. These qualitative insights were combined with sociometric measures from social network analysis to identify individuals who hold central positions in a faculty network. A focused case study of a pivotal faculty member illustrates how epistemological beliefs shape interpersonal influence and credibility across faculty status lines. Findings highlight the significance of individual beliefs in fostering collegial connections and advancing the institutional spread of RBIS.

Keywords: epistemological beliefs; social network analysis; active learning strategies; collaboration

Introduction

The use of research-based instructional strategies (RBIS) is widely recognized as a means to improve academic performance and retention in STEM fields (Freeman et al., 2014). STEM departments operate under distinctive conditions, such as high research expectations, hierarchical roles, and heavier teaching loads for non-tenured faculty, that uniquely shape faculty epistemologies and social interactions. These factors make STEM contexts especially important for examining how epistemological beliefs and social networks influence the adoption of RBIS. However, the extent to which faculty adopt these practices may vary by tenure status (Kezar, 2013). While non-tenure-track faculty often face constraints in adopting research-based instructional strategies, tenured faculty typically have greater autonomy in their teaching, more established collegial networks, and broader access to institutional resources (Baldwin & Wawrzynski, 2011; Umbach, 2007). These factors can facilitate the adoption of active learning and collaborative instructional strategies by tenured faculty, as well as faculty engagement in professional discourse around teaching innovations. By contrast, non-tenured faculty may have limited influence over curricular decisions and fewer opportunities for sustained collegial interaction, which can hinder their participation in instructional reform efforts. Studies have shown that non-tenure-track faculty are generally less likely to employ active learning

techniques than tenured faculty, often viewing themselves more as employees than as agents of pedagogical change (Baldwin & Wawrzynski, 2011; Umbach, 2007). Additionally, part-time or contingent faculty have been found to use collaborative instructional strategies less frequently. Collegial interactions have been shown to facilitate the adoption of RBIS (van Staaden and Raubenheimer, 2015), but such interactions may be constrained by institutional hierarchies. Perceived disparities in working conditions between tenured and non-tenured faculty can limit opportunities for meaningful collaboration (Schwartz, 2017). Non-tenured faculty often report feelings of marginalization and a lack of clarity around their professional roles, prompting a desire for stronger peer networks and a greater sense of belonging in the academic community (Levin & Shaker, 2011). Yet the hierarchical nature of academic institutions often inhibits such collegial integration (Kezar, 2014).

One underexplored factor that may influence collegiality is epistemology, specifically, individual beliefs about knowledge and learning (Daniels, 2014). Epistemological beliefs are known to shape knowledge-sharing behaviors and engagement in professional discourse (Nussbaum & Bendixen, 2003; Weinberg, 2015). However, little research has explored the link between these beliefs and the social dynamics among faculty, particularly in relation to RBIS adoption. This study examines the interplay between epistemological beliefs and collegial interactions among tenured and non-tenured faculty members. By exploring this relationship, we aim to better understand how faculty beliefs about knowledge influence their participation in teaching-related discourse and, by extension, the spread of RBIS. Insights gained from this study may inform institutional strategies for supporting faculty development and enhancing instructional reform.

Theoretical framework

Role of Epistemology in Social Interactions

Social Exchange Theory (SET) posits that individuals form and maintain relationships based on the exchange of valued resources, including knowledge (Umbach, 2007). Applied to higher education, this suggests that faculty may engage in collegial interactions to share teaching-related knowledge, which can in turn promote the adoption of RBIS (Freeman et al., 2014; Kreber & Castleden, 2009; Weinberg, 2015). Knowledge-sharing involves the mutual exchange of both tacit and explicit knowledge, often resulting in the co-creation of new ideas (De Vries et al., 2006). Prince et al. (2013) outlined three stages of RBIS diffusion: **awareness**, **information**, and **reflection**. The awareness and information phases are inherently social, involving discussion, observation, and the active pursuit of pedagogical insights. The reflection phase, while more internal, is shaped by prior social exposure to teaching strategies. These stages highlight the centrality of knowledge-sharing in fostering instructional reform.

Given this reciprocal interplay between epistemology and knowledge-sharing behavior (Daniels, 2014), the epistemological beliefs of faculty members appear to be fundamental to understanding both faculty disposition to forge social connections generally and to engage in discussions centering on teaching practice in particular. Hence, there is a far-reaching need to investigate the association between the epistemological beliefs and the social networks of individual faculty members.

Epistemological Beliefs

Epistemological beliefs, defined as individuals' conceptions of knowledge, teaching, and learning, offer valuable insights into behavior that are not captured by content knowledge alone (Pajares, 1992). Unlike knowledge, which evolves with experience, beliefs are more stable and deeply ingrained, shaping memory, perception, and behavior (Nussbaum & Bendixen, 2003). Researchers variously describe these as *beliefs*, *attitudes*, or *teaching conceptions* (McKay & Rozee, 2004; Wong et al., 2009), but all suggest that such beliefs play a significant role in knowledge-sharing and teaching behavior. Whether treated as beliefs, attitudes, or conceptions, teaching-related epistemology may be relevant to faculty members' disposition to engage in social exchange. For instance, Nussbaum and Bendixen (2003) demonstrated that epistemological beliefs significantly influenced students' willingness to engage in discussion and argumentation. Specifically, students who believed that knowledge was simple and certain were more likely to avoid intellectual disagreements and less likely to participate in knowledge-sharing interactions. While that study focused on students, its relevance to faculty lies in the underlying mechanisms of belief: whether among students or professionals, epistemological beliefs shape individuals' openness to new ideas and their engagement in collaborative discourse (Weinberg, 2015). This parallel is particularly relevant to understanding differences between tenured and non-tenured faculty. Tenured faculty, who often experience greater professional security and autonomy, may feel more comfortable engaging in intellectual disagreement and adopting new instructional practices. In contrast, non-tenured faculty, whose positions may depend on student evaluations or administrative approval, might exhibit more cautious epistemological orientations—favoring established methods and avoiding contentious pedagogical debates. Thus, while originating in studies of students, these constructs remain relevant and transferable when examining how faculty beliefs influence social and collaborative behavior in academic settings.

Nespor (1987) developed a theoretically grounded, empirically supported framework for distinguishing teaching-related beliefs from factual knowledge. His work drew on two types of interviews: one focused on teachers' general principles about teaching and students, and the other on their specific explanations of instructional practices. From this analysis, Nespor identified four key features that differentiate beliefs from knowledge: *existential presumptions*, *alternativity*, *affective and evaluative loading*, and *episodic structure*. These dimensions form the foundation for our analysis of faculty epistemologies and their relationship to social interactions within academic networks.

Existential Presumptions. Epistemological beliefs refer to individuals' deeply held assumptions about the nature of knowledge, knowing, and learning. Unlike knowledge, which is typically based on evidence and can be revised in light of new information, beliefs are often more resistant to change and may not require empirical justification. One key feature of epistemological beliefs, according to Nespor (1987), is that they often include *existential presumptions*, assumptions about the existence of certain entities or truths that are treated as self-evident and unquestionable. Stark examples of existential presumptions are represented by beliefs in God or various conspiracy theories. In the context of teaching practice, existential presumptions might revolve around strong beliefs relating to student 'ability' and motivation, or lack thereof. For instance, one of the teachers interviewed by Nespor believed that students who failed to learn math did so because they were "lazy".

Alternativity. Another defining feature of epistemological beliefs is *alternativity*, the tendency to envision idealized realities that contrast sharply with present or past experiences. Nespor (1987) described these "alternative realities" as aspirational constructs, often ungrounded in empirical evidence or lived experience. Such beliefs reflect an individual's vision of what could or should be, rather than what currently is. For instance, one teacher Nespor interviewed imagined a classroom that

was child-friendly and fun, a vision that stood in sharp contrast to her own experience as a student. In this way, *alternativity* captures how educators conceptualize ideal conditions that may be far removed from their actual teaching contexts.

Affective and Evaluative Loading. Nespor (1987) argued that beliefs are often shaped by emotions and personal judgments and thus tend to carry more affective and evaluative weight than knowledge statements. These emotional and value-laden aspects of belief influence how individuals prioritize certain teaching practices. For example, in Nespor's study, three of four history teachers believed that teaching historical facts had little lasting impact on students' understanding of history, and as a result, they devoted less instructional time to factual content. This illustrates how affective and evaluative judgments can guide teachers' decisions about where to invest their time and energy in the classroom.

Episodic Storage. Nespor (1987) argued that beliefs often gain strength and legitimacy from personal episodes—memorable events or experiences that shape how individuals interpret subsequent situations. These episodes may stem from classroom encounters, formative teaching moments, interactions with students, or broader professional experiences. Unlike abstract knowledge, which is often generalized and decontextualized, episodic memory is tied to specific situations and emotions, making it more influential in guiding future behavior. For instance, a math teacher interviewed by Nespor, who had been teaching in a vocational school, frequently drew upon personal anecdotes when explaining certain concepts—highlighting how past teaching episodes directly informed his instructional approach to school, and was more willing to employ anecdotal evidence relevant to teaching certain topics.

Social Networks

Because social exchange theory is grounded in the idea that relationships involve the reciprocal exchange of valued resources (Emerson, 1976), it is essential to examine how faculty are socially connected. Social network analysis (SNA) provides a powerful method for exploring these connections, based on the premise that social life is shaped by patterns of relationships rather than isolated individuals (Marin & Wellman, 2011). In the context of higher education, SNA offers a valuable tool for investigating how faculty interact professionally and how these interactions may align with their epistemological beliefs (Carolan, 2013).

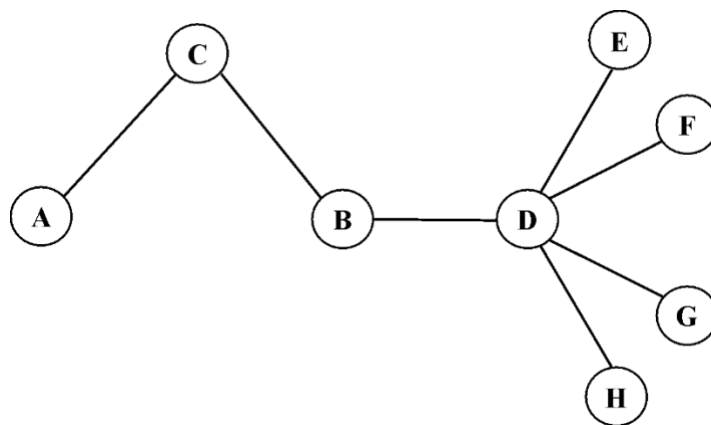
A core premise of social network analysis (SNA) is that an individual's position within a social structure shapes their opportunities and outcomes (Carolan, 2013). From a sociometric standpoint, individuals who are centrally located in a social network are thought to possess strategic advantages, such as access to information, influence or visibility. To capture these aspects of centrality, researchers commonly use measures such as **degree**, **closeness**, **betweenness**, and **eigenvector value**. These metrics help identify those individuals who are highly connected, centrally located, and potentially influential within the network.

The easiest way to conceptualize these measures is through the use of a graphic representation to illustrate each measure (Figure 1 below). *Degree* is in some sense a measure of the popularity of an individual and is equal to the number of node neighbors a focal individual possesses. For instance, in Figure 1, node D is linked to five neighboring nodes and thus has a degree of 5 (the highest in this network), whereas node A with just one connection has a degree of 1. *Closeness* represents how close an individual is to other actors in a social network and serves as an indication of the number of steps (i.e., how fast) information will spread from one actor to everyone else in the social network (Freeman,

1979). Examining closeness for node A gives us the following: the distance from node from A to C is 1 step, A to B is two steps, from A to D is 3 steps, from A to E (F, G, H) is 4 steps. To calculate closeness for node A then, we take the inverse of the sum of all distances (steps). *Betweenness* can be viewed as a measure of the extent to which a vertex plays a bridging role in a network. Bridging positions reflect power, because the person in this position serves as a gatekeeper of information (Freeman, 1977). For instance, node D is along the shortest path between nodes B and E, F, G, and H, and has a strong bridging position since it is in total control of information flow through the network. Finally, *eigenvector values* measure a nodes importance while taking its neighbors into consideration i.e., it measures how many connections its neighbors have (Bonacich, 1987). Thus, nodes A and E (F,G, H) have the same degree value being directly connected to one node (C and D respectively), but their eigenvector values differ based on the nature of those connections. Node D (directly linked to node E) has more connections than does node C (linked to nodes A and B). As a result, node E has a higher eigenvector value than does node A, despite having a similar degree.

Figure 1

A Sample Social Network Graph in Which Each Circle (node) Represents an Actor, and Lines Between Nodes Indicate Relationships.



Note. Centrality measures such as degree, closeness, betweenness, and eigenvector value can be derived from the structure of these connections.

This study examines the alignment between faculty members' epistemological beliefs and their sociometric measures of centrality to better understand individual contributions to the diffusion of research-based instructional strategies (RBIS) at the institutional level. Then, drawing on Nespor's framework, we explore teaching-related epistemological beliefs as expressed through faculty members' reflections on their experiences with RBIS and teaching more broadly. By applying social network analysis, we aim to uncover how these beliefs may relate to their sociometric measures of centrality.

Methodology

This study is part of a broader initiative funded by the National Science Foundation to improve undergraduate STEM education. The specific goal of this project was to foster cultural change among

faculty and administrators by promoting the diffusion of research-based instructional strategies aimed at enhancing students' quantitative literacy. To catalyze this shift, we adopted a generative approach that included a range of semi-structured opportunities for professional discourse. One of these involved regular bi-weekly, casual lunch-time sessions with unique topics of discussion centered around STEM pedagogy. At these events, STEM faculty were able to interact with colleagues from a broad range of disciplines other than their own. Although the ostensible intention of these events was to provide information about teaching innovations, the primary purpose was, in fact, to create opportunities for faculty networking and sensemaking. This paper presents a focused case study of one department—Physics—whose faculty participated most consistently in these pedagogical discussions.

Research Design

This study employed a qualitative design, using semi-structured interviews to explore emerging themes related to faculty members' epistemological beliefs and pedagogical practices. This approach is particularly well-suited for exploratory research and enables in-depth thematic analysis of participant perspectives.

The focal department comprised 13 full-time faculty members, of whom 11 participated in interviews conducted between 2019 and 2021. Each interview lasted up to 40 minutes and followed a semi-structured protocol, allowing for both consistency across participants and flexibility for follow-up questions and reflective dialogue (Patton, 2002). The interview protocol included a set of standard questions around curriculum decisions, approaches to teaching, views on student learning and departmental dynamics, which were designed to elicit their epistemological stance on pedagogy, including the use of research-based instructional strategies (Raubenheimer, 2004).

All participants were faculty affiliated with the Department of Physics and Astronomy at a large university in the Midwestern United States, and pseudonyms were used to protect their identity. Amongst these were seven tenured and four non-tenured members, who varied with respect to their teaching and research responsibilities. Except for one, non-tenured faculty members had no formal research load, while tenured faculty members carried discipline-focused at either level I (the highest research load) or II research load (a moderate research load). The single non-tenured faculty had research level III which refers to educational research within the discipline and thereby provides greater exposure to pedagogy related scholarship.

All interviews were transcribed and subsequently analyzed using qualitative data analysis software NVivo (Version 12.6). In the first phase of interview analysis, we examined the transcripts to determine faculty preference for teaching methods as a main vehicle to engage students and a starting point to categorize instructors as either lecture-oriented or active teaching-oriented. To capture the preferred pedagogical approach, we focused on phrases in the transcripts that explicitly outlined favored teaching strategies. In the second phase of interview analysis, we relied on Nespor's framing features which distinguish epistemological beliefs from knowledge. Since this was a novel application in studying epistemological beliefs of faculty, the semi-structured strategy was appropriate to enable spontaneity in shaping the dialogue and to stimulate additional details, such as existing social connections with other faculty members.

Using a deductive approach, we coded narratives based on Nespor's four features or broad codes (Miles & Huberman, 1994). With the broad codes entered as nodes (i.e., existential, alternativity, affective, and episodic storage), two authors jointly coded one interview to produce an initial version of the coding system. This analytical step in thematic coding, marking the inductive coding (Glaser, 1992), revealed potential sub-themes for which a set of sub-codes were developed within each broad

category. Sub-codes were entered as child-nodes in NVivo and used to match the sub-codes with the appropriate segments of text (Table 1). Using this system, the first and the second authors independently coded the transcript of another faculty member and met to compare coding and discuss any discrepancies. In general, the coders identified the same passages and the same broad codes but differed in some of the categorizations at the level of sub-codes. All of these discrepancies were resolved through discussion and definitions for sub-codes were further refined. To establish interrater reliability, these same authors coded broad- and sub-codes for a further two interview transcripts. Interrater concordance was 90% and 82% at the level of broad and sub-codes, respectively, a level of agreement that gave us confidence that the coding system could be reliably applied to the balance of the interviews. A summary of the coding scheme is presented in table 1 below.

To complement interview data on social ties and to gain measures of centrality, we employed a sociometric method, social network nomination approach, which has been shown to have high validity (Rogers, 1995). Faculty were asked to complete a sociometric questionnaire distributed via email across all STEM departments. This questionnaire was used to collect professional information and the “who talks to whom” about teaching practices across STEM fields, so-called network nomination data. Each faculty member was offered a series of questions related to the use of RBIS and asked to nominate faculty members with whom they most often discussed teaching related issues. Responses from the social nomination survey were compiled into an adjacency matrix representing teaching related interactions among faculty. Using these data, we constructed a network graph and calculated centrality measures of network position (for example, degree) to capture participant’s embeddedness in the teaching discussion network.

In the final stage of the data analysis, we aligned epistemological sub-codes with faculty preference for the dominant teaching approach and matched these associations with the sociometric data for each faculty member. Rather than analyzing these datasets in isolation, we iteratively compared and interpreted centrality measures alongside the epistemological profiles. This interpretative integration allowed us to examine whether individuals with similar epistemological orientations occupied comparable network positions, and how specific belief patterns might influence social connectedness and knowledge-sharing behaviors.

Table 1

Application of Nespor's (1987) Epistemological Frame to STEM Teaching

Description of Broad Codes/Domains	Emerging Sub-codes	Descriptions of emerging sub-codes	Identifying words for broad domain	Reflection statements representing emerging sub-codes
Existential Presumptions: assumptions treated as concrete truths, often categorical or non-negotiable. Statements are usually structured as facts that are not subject to dispute. Some radical or categorical ideas may serve as a good example of existential presumption.	Firm	Statements reflect instructor's intent to assume sense of ownership and instructor's expectations from students	"in my view", "I believe", "I think"	"I think, actually, my view is that we need to focus on teaching students skills, especially in STEM." (Finley interview)
	Fatalistic	Statements reflect instructor's intent to relinquish ownership		"So, the curriculum is lacking." (Finley interview)
	Declarative	Statements reflect instructor's intent to limit their involvement in tasks		"And I see those invitations to the lunch meetings. I keep ignoring them simply. This is my choice." (Azariah interview)
Alternativity: representations of alternative reality that a person had not experienced or that contrasts lived experience. This feature of belief systems plays an important role in defining a goal and task. Statements are structured as if information is still being processed and can be disputed. They convey a tone of wishful thinking with respect to reality.	Divergent	Statements representing alternative realities without experiential basis (without rationale).	It is less about buzzwords and more about the overall speculative tone of the statement that longs for alternative solution	"Yeah. I don't know who it has to go to after this, but we cannot implant it right away. We might have to add more hours for the student." (Finley interview)
	Convergent	Statements representing alternative realities based on experience (rationale is provided).		"Yeah, I'm kind of troubled, we have to graduate the students in four years or as best as possible. Why?" (Finley interview)
Affective and Evaluative Aspects: important regulators of the amount of energy expended (by teachers or learners) on certain content or activities.	Skeptical	Statements that communicate teaching is not	Less about buzzwords, more about tone of the statement that either	"So just going out and trying to invite people, bring people to us, didn't work so far." (Azariah

		worth the expended energy.	encourages or discourages an individual to spend time doing something	interview)
	Constructive	Statements that communicate that teaching is worth the expended energy.		“So, I think for the major it's always good to have a project [...] so we give them a project and ask them to work on this project, this could be helpful for them.” (Finley interview)
Episodic Storage: critical episodes that color the comprehension of subsequent events	Cursory	Surface-level statements referencing critical episodes without providing a rationale.	“for an example”, “I used to know”, “some time ago” some word that explicitly references the past	“Yeah, because in one class four or five years ago I had similar questions on Mars.” (Dana interview)
	Detailed	Detailed statements referencing critical episodes as a rationale for teaching choices. (goes beyond teaching)		“I can tell you an example. I had a student, actually an undergraduate student who worked in my lab [...]” (Finley interview)

Note. Broad codes and emerging sub-codes were derived from detailed analysis of faculty interviews.

Research Findings

Overview

The purpose of this study was to investigate associations between faculty epistemological beliefs and the social network of faculty members, discussing teaching, learning, and potentially RBIS. By focusing on a single department, experiences are not oversimplified. Rather, in-depth examination of faculty beliefs of teaching practices provides a chance to identify institutional strategies that can promote social interactions among faculty members.

Overall, we found that non-tenured faculty expressed a concern with teaching overload and insufficient institutional support. Yet much of the analysis shows that tenure is not the predictor of a faculty member's disposition to engage in research-based instruction and to create a strong peer network. Contrary to prior research, non-tenured members see active practices as being more central to their teaching methods, whereas their tenured colleagues value lecture as a dominant approach that covers content. At the same time, tenured members are more likely to see authentic research as a crucial element that engages students' long-term commitment to the field of physics. The porous boundaries for non-tenured faculty encourage some faculty to engage in activity other than teaching, for instance disciplinary research. Through research involvement, non-tenured faculty may gain social connectivity with tenured peers, which enables them to act independently, engage in curriculum development, and diffuse research-based instruction.

We organize our results below according to the two different types of analyses conducted (namely, qualitative and social network analysis) and include illustrative passages from interviews and sociometric measures to support our findings.

Interview Findings and Discussion

Categorization of Faculty Based on Their Dominant Teaching Approach

We identified six instructors who preferred lecture as the dominant teaching method in physics, and who were thus categorized as lecture-oriented (LO). This group of instructors is represented exclusively by tenured faculty. Notably, this group of instructors also valued content coverage and clearly expected students to meet the class standards and follow the class structure. While they had higher expectations of their students, they were also concerned with students' ability to keep up with the pace at which the lecture material was presented. Although these instructors prioritized lecture as the primary mode of material transmission, they did not necessarily regard themselves as an authority in the classroom. Moreover, these instructors promoted deeper learning by facilitating independent thinking and having students derive formulae on their own. This group of instructors engaged heavily in physics research and strongly argued for student laboratory experiences and authentic research engagement as indispensable to maintaining student commitment to the study of physics. They also noted the distinction between students in the physics major who needed to have greater mastery over the subject matter, compared to those taking courses for general education purposes. However, they recognized the value of authentic experience as being valuable for both majors and non-majors alike.

Faculty who prioritized research-based instructional strategies as the preferred way of engaging students (5 out of 11) were categorized as active teaching-oriented (ATO). These instructors were less focused on simply covering content. Only one of these five faculty was tenured, with two having an explicit research load (tenured faculty, Ashley, at level II-disciplinary research and non-tenured, Emery, at level III-physics education research). To promote deeper learning, some of these instructors occasionally argued for student research opportunities, while others sought to

connect physics to real-world contexts. Some of these instructors did voice concern about needing to cover content but prioritized students' needs and learning above content coverage.

These results are partially concordant with some prior research which examined differences in the faculty academic expectations of students and the instructional styles of contingent and tenured faculty. While previous research identified definitive differences between tenured and part-time non-tenured faculty in the likelihood of their using active learning strategies (Baldwin & Wawrzynski, 2011; Umbach, 2007), no differences were found in fidelity of implementation between tenured and full-time contingent colleagues in that respect (Baldwin & Wawrzynski, 2011; Umbach, 2007). Umbach (2007) found that full-time non-tenured members differ from their tenured counterpart in only one respect: their expectations of students. Given that the non-tenured instructors described in this proposed study all hold full-time contingent teaching positions and continuing affiliations with a single institution, it logically follows that they should be as likely to engage in research-based instructional styles as research has previously shown for tenured colleagues at other institutions. Consistent with this prior research and rationale that follows, non-tenured faculty in this study do indeed exhibit a preference for active learning strategies as the dominant teaching mode. However, contrary to prior research, our results show that tenured colleagues are more likely to prefer lecture as a dominant method of teaching to cover the necessary content. At the same time, in this study tenured faculty also strongly argue for laboratory experiences and authentic research as a main vehicle for student commitment to physics. On a related note, they tend to have higher academic expectations of their students than do non-tenured faculty, especially of students who plan to major in physics, which is strongly corroborated by prior studies (Baldwin & Wawrzynski, 2011; Umbach, 2007). Examination of epistemological differences between lecture and active teaching-oriented faculty unmask important epistemic differences between colleagues at the individual level and provides additional insight into how to support interactions between faculty at different ranks to induce social exchange and adoption of RBIS at the institutional level.

Categorization of Faculty Epistemological Beliefs Based on Nespor's Frame

The general categorization of faculty members into broad groups of lecture-oriented (LO) and active teaching-oriented (ATO) proved to be a fair predictor of epistemological beliefs of faculty members, which were analyzed as previously described, using Nespor's delineation of four features namely, existential, alternativity, affective and evaluative, and episodic storage (see table 1 above).

Existential presumptions were prominent in the interviews of all 11 faculty colleagues (see examples for exact quotes in Table 1). However, faculty manifested different dimensions of existential or indisputable presumptions; some tended to assume full responsibility for learning outcomes (*firm*), some were more likely to place responsibility for learning outcomes on students or the curriculum (*fatalistic*), while still others marked out their priorities (*declarative*).

Finley, a tenured faculty participant, emphasized that instructors need to focus on developing students' STEM skills to enhance their learning experiences. She explained that faculty are responsible for ensuring students acquire the skills necessary to succeed in undergraduate Physics. These statements were categorized as *firm*. Finley stated:

I think, actually, my view is that we need to focus on teaching students skills, especially STEM. I believe some affect the way we teach classes but doesn't really give the student skills. They need more than just information. So, in my view, science teaching is different – how to develop their skills, how to learn the method of teaching and thinking, more than just information. ... We show a student how to solve the problem, but I understand they

need very much help to know how to solve it because we don't teach them how to think. They never see it before. They can't do it, ...

The second dimension of existential presumptions was manifested through statements that placed responsibility for learning outcomes on students or on the curriculum. Karlo (pseudonym) expressed a belief that students invest little to no time into a course and fail to learn as a result. These statements were categorized as *fatalistic*. As Karlo explained, “[students are encouraged to practice more in class] since they really seem to struggle doing anything outside class to figure things out.”

A third dimension of existential beliefs involved faculty members' inclination to get involved in certain tasks not strictly research-oriented or more teaching focused. Azariah (pseudonym) decisively stated that their time is spoken for, therefore they did not get involved in meetings where faculty discuss reformed pedagogical strategies. These lunch meetings, organized by the department to foster discussion around teaching innovation, were perceived by some faculty as peripheral to their core professional responsibilities. Azariah's comments reflected a clear boundary between research and teaching commitments. These statements were categorized as *declarative* because agency for performance outcomes is being assigned to neither the instructor nor the students. Nonetheless, faculty clearly express their disposition toward certain tasks. Azariah explained: “And I see those invitations to the lunch meetings. I keep ignoring them simply. This is my choice.”

Alternativity was a less conspicuous feature in the interviews overall. While wishing for an alternative reality, some faculty members provided a detailed description of alternativity based on actual experiences (*convergent*). In contrast, others offered more hypothetical or idealized accounts detached from real practice (*divergent*). Finley was one of the few members whose narrative was rich in alternative statements. They believed that changing the way students are assessed would impact the quality of learning. During the interview, Finley reflected on departmental assessment practices and described specific ways they would modify examinations to emphasize conceptual understanding over rote problem-solving. These statements were coded as convergent because they were supported by evidence of being experienced or implemented. As Finley explained:

For example, if you made our exam to test a student's understanding just to really see what the student understands. It might be tough in the beginning, but if the student sees they are not going to pass this course and have an understanding of material, they would do this. In my view, actually, if [I] really want to make a change, I would change the exam. ... I would make the exam depend on the concept.”

In contrast, when Emery recalls their graduate experience, they remember wishing for a different type of teaching. Although they wanted it to be different, they could not define in what specific way it should be so. Statements consistent with this expression of alternativity were coded as *divergent* because they lacked evidence of being experienced. As Emery reflected, “So, I learned about active learning by taking higher [education] courses while I was in grad[uate] school. I did that because I didn't like the way I was being taught throughout my degree program, up until that point. At least that, you know, in part, knowing that there was something better that could be done, just didn't know what to call it.”

Affective and evaluative beliefs were less prominent than existential beliefs, but still conspicuous in faculty interviews. Since affect and evaluation regulate the amount of time and energy expended on teaching certain content in a particular way, interviews were screened for text consistent with this category. When faculty considered some material or activity worth doing, we coded it as *constructive*. As one faculty member stated, “And what we believe in our committee is just doing our job—

teaching really well—is what we need. It’s important that we communicate to the student. How we communicate to the students. Are we making them see the value surrounding physics?” (Finley).

In contrast, when faculty expressed doubt about the value of a particular activity, we coded such statements as *skeptical*. For instance, one participant questioned the usefulness of departmental outreach efforts, saying:

So, we’re to do that. But at the same time, we realize that really good, strong teaching is probably the best advertisement for our department. So just going out and trying to invite people, bring people to us, didn’t work so far [our colleagues felt that good teaching is the best advertisement rather than marketing the department] (Azariah).

This skepticism reflects the participant’s belief that effective teaching, rather than outreach or marketing, is the most reliable way to attract and retain students. Therefore, their doubt about outreach efforts led us to code these statements as *skeptical*.

Episodic storage was pronounced in all interviews. When faculty members explicitly drew on past episodes from their life to frame their responses, we coded it as *detailed* or *cursor*y depending on the level of detail provided. Some faculty were extremely detailed in drawing on past experiences. For instance, Dana (pseudonym) used several specific examples from the past in response to any question posed to them. In response to a question focused on priorities for undergraduate teaching and learning, Dana went into extensive description about their early teaching experience when they incorporated daily assignments into a grading system to encourage students to be diligent about homework. These comments were coded as *detailed*:

I had that problem last year before they decided to screw with the system is, for whatever reason, they stuck me in an active learning classroom where the tables were sort of like this big, but then three of them stuck together. And then at each one of those three people sat, which for group work is perfect. But I want to give an exam, there’s no way to do that. So, I said, well, I can teach in this room, but for each one of those little things I can only have one student, so I could only have one third the number of students the room is designed for. Oh, no, that’s not acceptable. So fortunately, I got moved. But it’s like, why do I have to fight this fight, getting a classroom to teach a class seems like a default for the university, not something you have to struggle for every semester (Dana).

In contrast, *cursor*y comments were less elaborate and circumstantial, providing quick reference. For example, one participant noted the challenges of classroom modernization, saying:

Well, they’re aware of the issue of the lack of modernization in classrooms, right? They’ve been trying to address that, but they’ve been addressing that while they’ve been tearing down buildings. So now we don’t have enough classrooms (Gabe).

This response illustrates a *cursor*y recollection because it refers to past events without detailed description or personal elaboration.

Table 2 shows the percentage of passages associated with each of the sub-codes. All faculty members' responses contained epistemology consistent with existential or indisputable presumptions. That is not surprising given that existential presumptions are related to beliefs about teaching practice and student ability. Moreover, the percentage of text consistent with *firm* existential presumptions was the highest across all sub-codes once averaged among participants (22. 2%). It was also the most frequently encountered code for over half of the participants (Table 2). Moreover, most of those participants were coded as lecture-oriented (LO) during the first phase of the data analysis. Interview narratives of all participants that were categorized as LO manifested at or above 20% of passages consistent with the existential presumptions *firm* code.

Shaded in grey in Table 2 is the sub-code that was most highly expressed in each participant. Most of the passages were categorized as representing the *firm* existential presumptions sub-code, which characterized their sense of ownership for learning. The episodic storage sub-code, which characterized over-reliance on past experiences in interviews, was frequently found but does not serve as a fair predictor of faculty orientation towards research-based instruction.

Table 2

Passages of Text Coded in Each Category and Sub-Category (Expressed in Percentage)

Broad Codes			Existential			Alternativity		Affective		Episodic Storage	
Sub-codes Percentages			Firm	Fatalistic	Declarative	Convergent	Divergent	Constructive	Skeptical	Detailed	Cursory
Name	Tenure status	LO or ATO*	Percentages								
1. Miles	T	LO	40.6	2.6	1.9	2.4	0.5	8.0	0	9.7	3.5
2. Layne	T	LO	23.5	8.9	1.7	1.3	0	4.7	2.3	4.2	5.0
3. Finley	T	LO	27.6	17.2	0	19.1	2.6	10.2	4.6	9.2	5.6
4. Dana	T	LO	26.2	4.2	2.3	6.3	0	14.3	13.0	65.0	3.6
5. Azariah	T	LO	30.0	3.5	28.1	3.0	0.6	17.2	10.5	13.5	1.5
6. Harper	T	LO	19.3	13.8	0	0	0.2	10.6	3.6	9.9	0.4
7. Emery	NT	ATO	31.2	0.5	0.5	10.2	6.0	23.7	4.1	21.8	0.5
8. Avery	NT	ATO	13.8	12.1	0	8.0	0.9	14.8	9.9	26.8	0
9. Karlo	NT	ATO	12.1	12.5	0	8.6	0	18.1	3.1	12.0	4.3
10. Gabe	NT	ATO	7.9	3.6	1.4	1.4	0	11.9	11.7	21.9	0.9
11. Ashley	T	ATO	12.3	2.8	0.6	20.4	4.6	33.6	14.9	15.2	2.8
Average %			22.2	7.4	3.2	7.3	1.4	15.2	7.0	19.0	2.6

*LO or ATO = lecture-oriented or active teaching-oriented
Note: Because some lines were assigned to multiple emerging sub-codes simultaneously, percentages may not add up to 100 for a given faculty member.

In summary, all LO faculty members (with one exception, Dana) were characterized by their *firm* epistemological statements reflecting their intention to assume ownership for learning outcomes and higher expectations of their students. While Dana was just as high in their expression of ‘firm’ epistemology (26.2%) as the rest of their LO colleagues, *firm* was not the most expressive epistemology for them. The only ATO faculty member who was similarly highest in *firm* epistemology was Emery.

Participation records for biweekly lunch time presentations and discussion around STEM pedagogy show that non-tenured faculty tended to participate more regularly in networking opportunities than did tenured faculty (Table 3).

This suggests that non-tenured faculty are willing to devote time to learn about new active learning pedagogies and to network with colleagues. All of those who did not attend any session were tenured faculty with higher research and service obligations. Only one of the lecture-oriented faculty, Finley (tenured), was a regular attendee, suggesting an openness to the possibility of new teaching approaches. Dovidio et al. (1988) demonstrated that differential power factors influence nonverbal power displays. It could also be that differences in tenure status and ensuing power relations may affect event participation of faculty members. Status differences have been shown to emerge from various sources or dimensions (Thomas-Hunt et al., 2003). In this study, colleagues differ with respect to tenure status and sub-disciplinary affiliation. It is possible that perceived expertise associated with tenure status influences the likelihood of faculty attending networking events (Thomas-Hunt et al., 2003). Whereas the majority of attendees were not tenured, all non-attendees were tenured. Sub-disciplinary affiliation (physics or astronomy) may serve as a tentative explanation for differential attendance of events and socialization, since the majority of the attendees were astronomy faculty (Karlo, Gabe, Avery, Ashley) and the majority of non-attendees were physics colleagues.

Table 3

Faculty Participation in Networking Events Over Several Years

Name	Research Level	Teaching Orientation	Tenure Status	Events Attended	Subdiscipline
Karlo	None	ATO	NT	29	Astronomy
Finley	I	LO	T	27	Physics
Avery	None	ATO	NT	24	Astronomy
Ashley	II	ATO	T	23	Astronomy
Gabe	None	ATO	NT	16	Astronomy
Emery	III	ATO	NT	6	Physics
Layne	II	LO	T	1	Physics
Leslie	I	-	T	1	Physics
Dana	II	LO	T	0	Astronomy
Harper	II	LO	T	0	Physics
Murphy	I	-	T	0	Physics
Azariah	I	LO	T	0	Physics
Miles	I	LO	T	0	Physics

As noted previously, it has been suggested that epistemological beliefs affect individuals’ disposition to engage in knowledge-sharing behavior and networking (Weinberg, 2015). Our analysis of epistemological beliefs showed that tenured faculty advocated for research and lab experiences to

engage students in physics and showed higher representation of *firm* existential beliefs than did non-tenured colleagues. Both findings potentially point to a more fundamental epistemology in tenured faculty relative to the majority of non-tenured members. Given the reciprocal interaction between epistemology and knowledge-sharing behavior, differences in *firm* existential epistemology may differentially influence participation of members and their attendance at networking events. An additional explanation possibly addressing the latter is the time constraint that both tenured and non-tenured members mention in interviews. According to Emery, time constraints are especially true for faculty who are active in research (level I or II) and handle upper major courses. While tenured members with active research are expected to have a higher engagement in cognitive discourse and networking (Jehng et al., 1993; Kienhues et al., 2008; Thomas-Hunt et al., 2003), time constraints may explain lack of engagement in networking events.

Social Network Analysis of Faculty Teaching Relationships

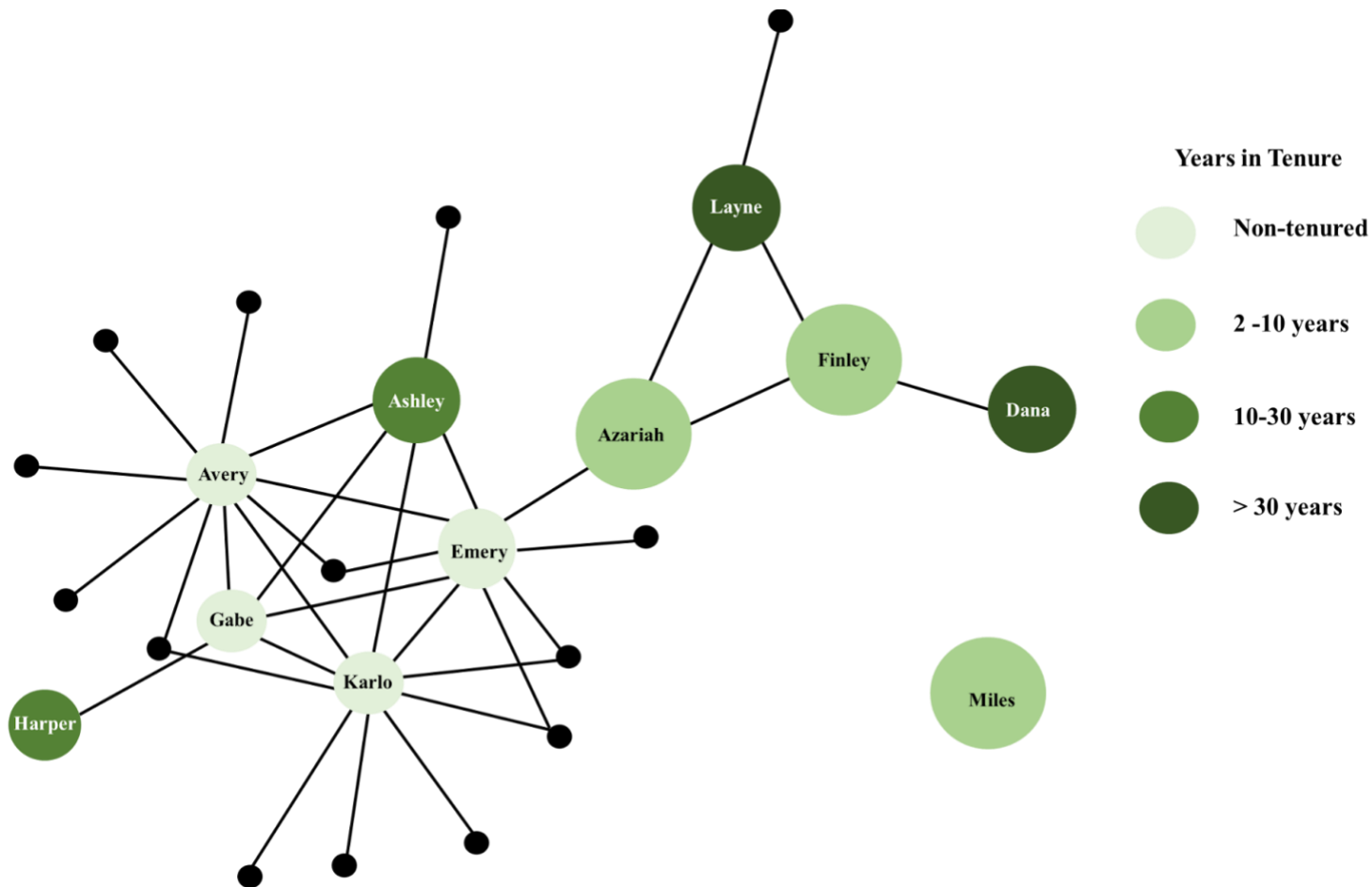
Having established the epistemological orientations of the faculty, we next examine how these orientations align with the structure of the teaching-related social network. Because the goal of this study is to understand the relationship between epistemology and social connectedness, our analytical design treats the qualitative and quantitative components as interdependent rather than parallel. The epistemological profiles provide the interpretive framework for understanding patterns in the centrality measures, and the network metrics, in turn, offer structural context for the epistemological stances. Thus, the analyses that follow reflect an integrated mixed-methods approach in which both datasets are interpreted jointly rather than separately.

Social Network Relationships. The social network in this study (Figure 2) illustrates interactions among faculty members with respect to teaching. Social survey responses provided us with data concerning faculty teaching connections to others in their department as well as with STEM faculty outside of the unit. Using this information, we created a social network graphic (Figure 2) including indicators for the number of years in tenure and research responsibilities. Thus, Karlo, Avery and Gabe are non-tenured faculty with no research responsibilities. Emery is the non-tenured faculty with the research responsibility (hence larger circle size). Small dots in the image are external STEM faculty that have been identified as connections by the faculty of interest in this study, i.e., some faculty also maintain connections to colleagues outside of their department.

Using this graphic, it is possible to visualize the network patterns and to conceive of the avenues through which physics faculty members are engaged in conversations related to innovative teaching pedagogy. For example, Dana, Finley, Layne and Azariah, all categorized as lecture-oriented faculty on the basis of interview data, form a distinct social cluster on the basis of social network survey data, whereas Avery, Karlo, Gabe, Ashley, and Emery, characterized primarily as active teaching-oriented faculty, along with Harper (LO), form a second distinct cluster. Miles was categorized as lecture-oriented but forms a separate and isolated node. We can infer from the configuration that any interaction between these two main clusters likely occurs through Emery; categorized as active teaching-oriented faculty but who shares the higher percentage of *firm* epistemological beliefs common to lecture-oriented colleagues. Since Emery is connected to just one faculty member in the lecture-oriented cluster, any dissemination of active teaching-oriented ideas is entirely dependent on the link between Emery and Azariah.

Figure 2

Teaching Related Social Network in the Physics Department



Note. Circles indicate faculty members within the Physics department, and small dots represent STEM faculty identified as external contacts. Circle size reflects faculty research load (the larger the circle, the heavier research responsibilities). Circle color corresponds to the number of years post-tenure (the darker, the longer).

Measures of Centrality. To examine how well the social network matches epistemological orientation, we measured several centrality parameters for each faculty member (Table 4) namely, degree, betweenness, and eigenvector value. As previously explained (see Methods section) Calculating closeness requires that we sum up all the distances (steps) that separate faculty members and take the inverse of it. However, since Miles is not connected to anyone, that distance is infinity, the inverse of which yields zero, rendering it impossible to use closeness as a measure for the current network.

Table 4

Centrality Measures Reflecting Social Connectedness

Name	Miles	Layne	Finley	Dana	Azariah	Harper	Emery	Avery	Karlo	Gabe	Ashley
Teaching orientation	LO	LO	LO	LO	LO	LO	ATO	ATO	ATO	ATO	ATO
Degree	0	3	3	1	3	1	9	10	10	5	5
Betweenness	0	22	22	0	76	0	122.5	92.5	80	22	22
Eigenvector value	0.00	0.05	0.05	0.01	0.21	0.14	0.97	0.96	1	0.74	0.74

Centrality metrics were interpreted in relation to participants' epistemological orientation, allowing us to examine whether individuals with similar epistemological profiles occupied similar structural positions in the network. The analysis reveals that epistemological orientation is not only correlated with but may shape social network positioning by influencing individuals' engagement in teaching conversations. As can be seen in Table 4, lecture-oriented faculty (Miles, Layne, Finley, Dana, and Harper) holding more *firm* beliefs may be less inclined to form diverse teaching-related connections, thus resulting in lower centrality. Azariah is a lecture-oriented faculty but measures relatively high in betweenness because they influence the information flow between the rest of the lecture-oriented faculty and Emery. Avery, Karlo, Gabe, and Ashley (categorized as active teaching-oriented) have the highest number of ties to faculty within physics and across other STEM departments, as reflected by the highest degree values for all five of them. Three of these faculty (Avery, Karlo, and Emery) also have noticeably high betweenness measures, indicative of their influence on the information flow, as well as high eigenvector values, which signifies that they are more approachable members. This pattern suggests that epistemological stances act as filters or boundaries for social interaction, where openness to alternative teaching methods (reflected in active teaching-oriented epistemologies) facilitates broader network ties and centrality.

Although Emery may not have the highest number of connections of the three social faculty, they possess the highest betweenness value of all faculty members (122.5), marking them as a compelling social influencer. What is particularly interesting about Emery is that while broadly categorized as active teaching-oriented, the epistemological orientation in their interview narrative manifests a high

percentage of *firm* beliefs, a characteristic otherwise observed among lecture-oriented faculty. Their *firm* epistemological beliefs also reflect higher expectations of students who they are convinced benefit from early research experiences. Since epistemology may be one of the sources that influence knowledge-sharing behavior among individuals (Nussbaum & Bendixen, 2003; Weinberg 2015), variation in *firm* existential beliefs may explain differential social measures among faculty. This variation may serve as an explanation for Emery's high betweenness value due to their unique connection to an LO member (Azariah). One plausible explanation for Emery's unique connection to an LO member is their graduate teaching background and current investment in physics education research, which places them in a unique position to suggest viable teaching alternatives to the LO group. Since they are actively engaged in educational research, Emery has dedicated time and resources to the development of course curricula and teaching strategies. Together these create a strong educational and research base from which to interface effectively with both LO and ATO faculty members.

In the last section which follows, we delve deeper into Emery's narrative using passages from their interviews to explain their unique position as a bridge or 'connector' between active teaching oriented and lecture-oriented colleagues in the unit. In contrast, Harper, broadly grouped with lecture-oriented faculty on the basis of their interview text, is not linked to any member of this cluster, but is connected to a single ATO faculty member (Gabe). Notably, epistemological orientation in Harper's interview manifests a lower percentage of *firm* beliefs than is characteristic of lecture-oriented members in general, which may go some way to explain their relative removal from the LO cluster. It appears that individual faculty epistemologies, specifically *firm* existential beliefs, may explain members' affiliation with certain social groups.

Emery's Case and General Discussion

Our research question asked how teaching-related epistemological beliefs of faculty members explain their knowledge-sharing behavior and sociometric values. Prior work supports a relationship between epistemological beliefs and individual engagement in intellectually stimulating environments that provide opportunities for reflection (Jehng et al., 1993; Kienhues et al., 2008; Valanides & Angeli, 2005), suggesting that such beliefs contribute to social interactions among individuals and drive knowledge-sharing behavior (Weinberg et al., 2015). Consequently, to the extent that faculty members differ in their teaching-related epistemological beliefs, they are hypothesized to differ in their likelihood of engaging in social exchange of knowledge related to pedagogy.

In this study, faculty differed in their prioritization of lecture over active teaching methods as a way of engaging students, dividing them into two broad groups of lecture-oriented and active teaching-oriented members. The majority of active teaching-oriented colleagues are non-tenured faculty members with heavy teaching loads, who are interested in employing innovative teaching strategies. Despite the fact that tenured faculty professed their commitment to lecture as the dominant teaching mode, they were more likely to advocate for active research and authentic lab experiences as two settings indispensable for the stimulation of student commitment to, and engagement with, physics. Early experience with research opportunities has been shown to impact STEM student retention, attitudes, and beliefs (Goodwin et al., 2021; Huziak-Clark et al., 2015). For instance, course-based undergraduate research experiences (CURE) provide undergraduates access to early research experiences, generally in psychologically safe class settings. Students who participated in a CURE reported higher levels of authentic learning than did inquiry students, where

software simulations were part of both experiences (Goodwin et al., 2021). In our study, tenured faculty familiar with the learning benefits of mentoring students in their research advocate for such experiences as a vehicle for student engagement and commitment to physics. It may be that mentoring in the context of authentic research experiences further grounds tenured faculty in the structure of the discipline, resulting in a higher expression of fundamental ‘firm’ epistemology and a more nuanced understanding of how to enhance the learning experiences of students (Schommer-Aikins & Hutter, 2002).

Thematic analysis of interviews demonstrates that tenured faculty members were more likely to assume responsibility for student learning outcomes than their non-tenured colleagues, and in return, expected more skills and commitment from majors and non-majors alike. These findings are consistent with prior research confirming that tenured faculty have higher expectations (Umbach, 2007) and may serve as evidence supporting more fundamental epistemology among lecture-oriented tenured faculty. At the same time, sociometric values for lecture-oriented faculty were lower than that for active-teaching oriented members, suggesting that the former are less engaged in interactions than the latter. Since epistemology drives knowledge-sharing behavior (Weinberg et al., 2015), it becomes important to address this dissonance. One possible explanation for the divergence between sociometric values and epistemology is the fact the LO group of faculty has a heavy research load and less time to attend networking events and to engage with colleagues in knowledge-sharing around STEM pedagogy. Non-tenured faculty, on the other hand, have no research load and dedicate virtually all of their time to teaching-related matters. Coincidentally, non-tenured faculty may have a paucity of research experiences that have been proven beneficial for students. The importance of striking a balance between the unique contributions of tenured and non-tenured faculty should be evident. Emery’s case is a telling example of how to balance the countervailing tensions imposed by the time constraints of a heavy teaching load and expertise integrating early authentic research experiences into undergraduate coursework.

Emery represents an interesting case that may provide some insight into how best to navigate this dichotomy. Having been grouped with the active teaching-oriented cluster, and having shared similar sociometric values, they appear also to manifest fundamental ‘firm’ epistemological beliefs typical of the lecture-oriented faculty. In common with the latter, Emery assumes ownership for student learning outcomes, explicitly advocates for early undergraduate research experience as a vehicle for greater student commitment, and has higher expectations of students than do their non-tenured colleagues.

[W]e provide a capstone experience, for example, for the majors to help them get that research experience started early. Have some outcome from it. You either [do] scholarly work, or at least exposure to being part of a research team, to prepare them for that graduate experience (Emery).

Their epistemology, reflected in ‘firm’ existential presumptions, allows them to transcend institutional boundaries imposed by faculty ranks and to exercise agency in collaborating with tenured faculty in designing curricula. Below they describe their interaction with a tenured faculty member (unique link to Azariah) in developing a new course. Emery explained:

I think we have good course offerings for our majors. But ... as a department, we've recognized that there are places we could really improve these courses that are ...being offered and change our curriculum. ...another professor and I went to ... a workshop over the summer, a couple years ago. And one of the courses we were working on ... a

computational physics course for undergraduates to help them get some experience early ... So that we could give them the basics and, ah, so that arose because of conversations we had.

What appears to support Emery's 'firm' existential presumptions is their involvement in physics education research, which in turn, ensures their credibility and status in the research community within the unit (that is, with Azariah, Finley, Layne and Dana). Their commitment to research as a vehicle for student engagement provides them a stronger lead into the lecture-oriented faculty camp. Like the majority of the other non-tenured colleagues, Emery is bounded by institutional limitations imposed by rank (Levin & Shaker, 2011) but appears to be finding a way around these constraints through their own educational research. One of the constraints mentioned by most faculty, regardless of their rank, was lack of time. Emery's involvement in physics education research creates the time and space needed to develop curricula or teaching approaches.

Non-tenured faculty tend to assume a heavy workload of teaching duties (Carvalho & Diogo, 2018), usually at the expense of research opportunities. Heavy workload impacts time and resources available to non-tenured faculty to engage in research on teaching strategies (Kezar, 2013). Additionally, there is little institutional incentive for these faculty members to engage in such work. The bulk of their teaching comprises introductory courses for non-majors, which affects the type of student enrollment (Baldwin & Wawrzynski, 2011). Many students enrolled in these courses consider them a requirement, rather than as offering something useful to learn. It is possible that this commonplace student perception and attitude in turn deters faculty from developing higher student expectations and manifests in lower expression of fundamentally 'firm' existential presumptions. Non-tenured faculty feel that they have little influence over students who do not wish to fully participate in a given course. Moreover, unsupportive institutional and departmental policies toward non-tenured faculty can result in poor curricular design and impact instructor preparation (Kezar, 2013), thereby removing social platforms that can promote discourse and solidarity across faculty ranks (Schwartz, 2017).

Emery's continued involvement in instructional development, driven largely by their research in physics education, may be producing a galvanizing effect which encourages ties with tenured faculty and allows them to serve as a potential bridge between non-tenured and tenured faculty. Additionally, this explanation resonates with Granovetter's (1973) theory supporting boundary-spanning relationships and their effect on the acceptance of alternative strategic choices by actors. Contacts who share the same operating contexts often provide little information different from actors' knowledge base. For instance, Finley and Dana share research-oriented context and their views are likely to resemble each other's. By contrast, Emery operates in both contexts, research-oriented and active teaching, and can provide the insight that is more novel, imparting significant informational influence on research-oriented faculty.

This strategy of enabling individual faculty agency within institutional limitations is supported by Karlo in their final response about engaging non-tenured faculty in research-based instructional development. They suggest reducing teaching loads to facilitate non-tenured faculty involvement in physics education research might support the adoption of research-based instruction by faculty more broadly. Karlo explained:

Yeah, I don't know. It's a tough thing, right? I mean, time is also an issue, right? Trying to maintain a research program and if nothing else. I mean, one way might be course releases or something so that you have a little bit lower teaching load so that you have time to try to

redesign things. Yeah, often you're on the treadmill and there's no time to slow down and recast things.

Why might it be important for non-tenure track faculty to be engaged in educational research when they already show a higher disposition toward using research-based instructional methods? Literature claims that non-tenured faculty function without sufficient autonomy as professionals, which constrains both their agency and professional identity, and reduces their credibility in the research community primarily represented by tenured colleagues (Levin & Shaker, 2011). As a result, they are more likely to perceive themselves as employees and be less committed to the institution (Levin & Shaker, 2011; Ochoa, 2011). It is possible that this lower commitment to the institution manifests as lower ownership for student outcomes as evidenced in their epistemological beliefs. Therefore, it is likely that research engagement of non-tenured faculty, a hallmark of tenured faculty, has the potential to contribute to boundary spanning relationships that unite two previously insular groups in efforts to broaden the implementation of research-based instruction. Ultimately, this approach holds promise for increasing the quality, quantity, scope of knowledge building, and diffusion of research-based instructional strategies at the institutional scale.

Conclusions & Implications

Epistemological and network analysis in one STEM department at a midwestern, research-intensive university, points to the importance of several factors for supporting non-tenured faculty. The analysis grouped faculty into two categories of lecture and active teaching-oriented members. Epistemological analysis elicited faculty respondents' perceptions regarding active learning strategies. While the majority of active learning-oriented colleagues were fully invested in and practicing this approach, lecture-oriented faculty advocated for authentic research as a nuanced path to making learning active and dependable but did not necessarily act on this belief. At the same time, the majority of active-learning colleagues were represented by non-tenured faculty who have greater teaching loads and are more resource limited than the average tenured colleague. Due to their teaching loads non-tenured faculty had no dedicated time to incorporating authentic research and are cut off from the educational research opportunities that facilitate exploration of early student experiences.

It would be fitting if institutional support were adapted to capitalize on the complementary skillsets and interests of tenured (LO) and non-tenured (ATO) faculty. This might entail providing non-tenured faculty with resources to work on curriculum and teaching strategies at a research level and recognizing the value of this expertise. At first glance this may appear to contradict the primary roles and responsibilities of the faculty ranks, blurring lines within the unit. However, many non-tenured faculty are already early adopters of cutting-edge pedagogies simply because of their stronger commitment to teaching, thus such a move might require little more than formalizing this function and minor adjustments in course loads. To the extent that institutional support provides LO and ATO faculty opportunity for intuitive reflection based on experience, these divergent epistemologies can combine to create an optimal solution for STEM teaching and student learning. While this study offers important insights, several limitations should be noted. The sample is drawn from a single STEM department at one institution, which may limit the generalizability of the findings to other settings. Additionally, social network data rely on self-reported connections, which could miss informal or unrecognized teaching interactions. The cross-sectional nature of the data captures a snapshot in time, limiting our ability to observe changes in faculty epistemologies or network positions over time. Finally, although the mixed-methods design integrates qualitative and

quantitative data, further methodological refinement could deepen understanding of the causal relationships between epistemological orientations and social network roles.

Building on these findings, future research could pursue several avenues to deepen understanding and enhance institutional support for STEM faculty. First, expanding the study across multiple STEM departments or institutions would enable examination of whether the observed patterns of epistemological beliefs, teaching practices, and network positions hold across diverse contexts. Second, longitudinal research could investigate how faculty beliefs and engagement with research-based instructional strategies evolve over time, particularly as non-tenured faculty gain experience or benefit from institutional resources. Third, intervention-based studies could assess the impact of targeted supports—such as dedicated time for curriculum development, teaching-focused resources, or mentorship programs—on fostering collaboration between lecture-oriented (LO) and active teaching-oriented (ATO) faculty. Finally, further investigation into how epistemological differences shape the diffusion of teaching innovations could inform strategies to optimize faculty networks, promoting equitable teaching practices and improved student outcomes. Together, these directions position the present study as a starting point for broader inquiries into the interplay between epistemology, social networks, and instructional change across diverse disciplinary settings.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. DUE-152562. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Beyond the Surface: Exploring Explicit Reflection in Nature of Science Education

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ABSTRACT

In science education, the concept of Nature of Science (NoS) is considered crucial to foster scientific literacy. Numerous studies underscore the significance of one key-component in effective Nature of Science education: Explicit Reflection. However, capturing the concept of Explicit Reflection presents a series of challenges. Research indicates that employing questions is a viable method to instigate reflection, yet the implementation of this approach exhibits considerable variability. Furthermore, the diverse interpretations of NoS education itself, ranging from the consensus view to more open perspectives, further complicate the educational landscape. This study addresses these challenges using two methodologies: a systematic literature review and expert content validation for the categorization of Nature of Science frameworks. Our findings show that articles favoring student-centered definitions of Explicit Reflection demonstrate more proficiency in their instructional approach to Nature of Science education by posing more and effective questions, with a particular emphasis on specific aspects of Nature of Science. In contrast, articles emphasizing teacher-centered definitions of Explicit Reflection present fewer and less effective questions within their instructional approach to Nature of Science education, often focusing on generalized reflections unrelated to Nature of Science. Furthermore, articles adopting Nature of Science frameworks categorized as *closed towards defining Nature of Science* are more likely to align with the patterns of articles that had a teacher-centered definition of Explicit Reflection. In contrast, articles containing frameworks that were more *mixed* or *open towards defining Nature of Science* mostly aligned with the patterns of articles having a student-centered definition of Explicit Reflection. To conclude, this study unveils the intricate relationship between the various meanings of Explicit Reflection, the conceptualization of Nature of Science, and Nature of Science questions. It promotes clarity in the field, facilitating a shared understanding of Nature of Science education and Explicit Reflection, vital for cohesive and impactful science education and research.

Keywords: Nature of Science, Explicit Reflection, NoS questions, Science Education, Systematic Review

Introduction

Within the realm of science education, the concept of Nature of Science (NoS) is deemed fundamental. NoS encompasses the values, assumptions, and essence of what science is and how it operates (Clough, 2006; Lederman, 1992). It is widely acknowledged that NoS education is instrumental for nurturing scientific literacy (AAAS, 1993; NGSS, 2013; NRC, 2000). Ever since Abd-El-Khalick and Lederman's influential review in 2000, the concepts of *implicit* and *explicit* approaches towards NoS education were coined. These concepts stress the importance of clear NoS instruction and the need for students to reflect on their learning experiences. As a result, the term *Explicit Reflection* (ER) has become widely used in NoS education research, with researchers like Krajewski and Schwartz (2014) and Lederman (2007) highlighting its significance.

There is considerable diversity in the definition of ER within the field of NoS education. For instance, while Aydin et al. (2013) emphasized that ER entails specific planning, teaching, and assessment in NoS education, Matkins and Bell (2007) focused on students reflecting upon the distinction between classroom science and the practices of real-world scientists. The variation in these definitions adds complexity to the teaching and understanding of ER within the context of NoS.

In light of the inherent challenges associated with ER (Gandolfi, 2017; Lederman, 1992), this article aims to address two of these challenges found within the literature.

Challenge 1: The Importance of Questioning

There are many ways to elicit reflection, but one common approach is to use questions targeted at ER (Kruse et al., 2020). Questions are the prompts that make students reflect and develop a rich conceptual understanding of NoS (Voss et al., 2022). Kruse et al. (2020) showed that a significant number of questions expected to evoke ER often fall short of their intended purpose. Instead, they tend to generate self-reflection among students, as opposed to a more profound reflection upon the very essence of NoS, which remains the heart of the matter.

Challenge 2: Consensus in NoS Education

The lack of consensus on what should be taught about NoS adds to the complexity of ER. On one side, the *consensus view* proponents believe in a set of NoS aspects that form the basis for instructing students about the fundamentals of NoS (Lederman et al., 2002; McComas & Clough, 2020). On the other side, adversaries assert that the consensus view offers too narrow of a perspective of NoS (Irzik & Nola, 2011; Kaya et al., 2016; Matthews, 2012). This divergence in conceptualizations prompts a pertinent question: when scholars and academics hold differing interpretations of NoS for science education, does this variation extend to their views on ER in NoS education? Do they approach it from distinct angles and conceptualize it in varying ways? The proliferation of diverse conceptualizations can inadvertently create confusion, not only among educators but also among researchers. Such confusion, if left unaddressed, can undermine the collective efforts to enhance the effectiveness of NoS education and research. Therefore, it is important to move towards transparency in the field.

The Goal of Our Study

Through a systematic review of existing literature, our goal is to provide clarity and a comprehensive understanding of the use of ER within the realm of NoS education research. In particular, our study seeks to address the challenges that surrounds ER and its application in NoS

education in two ways. First, we aim to unveil the connection between the numerous meanings attributed to ER and the types of questions that facilitate ER. Secondly, we explore the potential divergence between different NoS frameworks, and assess if and how an article's conceptualization of NoS influences its approach to ER and the choice of questions.

Theoretical Framework

Meanings of ER

Since Abd-El-Khalick and Lederman (2000) introduced the distinction between implicit and explicit instruction, the need for learners to reflect on their NoS experiences has gained prominence. Consequently, *explicit reflection* (ER) has emerged as a fundamental concept within NoS education research, emphasized by scholars such as Krajewski and Schwartz (2014) and Lederman (2007). However, ER's popularity is matched by its lack of a precise definition. It takes on various meanings. For instance, Aydin et al. (2013) suggested that ER involves NoS education that is “specifically planned for, taught, and assessed” (p. 990), Matkins and Bell (2007) rather emphasized that by using ER in NoS education, students “reflect upon the similarities and differences between classroom science and practicing scientists.” (p. 138). Therefore, while both authors aimed to elucidate the concept of ER, disparities in their definitions emerge. Furthermore, numerous studies fail to even provide any definition of the concept (Cil & Cepni, 2012; Deniz et al., 2020).

To study the different meanings of ER, Boven et al. (2025) conducted a systematic literature review that resulted in a concise summary that delineates **four analytical themes for ER** and their corresponding categories, providing insights into the multifaceted nature of ER. These themes unveil diverse perspectives and nuanced dimensions related to how ER is conceptualized within NoS education. The four analytical themes found are: *Meaning of Explicit*, *Meaning of Reflection*, *Learning Environment* and *Cognitive Processes Dimensions* (see Table 1).

Table 1

Analytical Themes of ER and Their Different Interpretations (Boven et al., 2025)

Meaning of Explicit	Meaning of Reflection	Learning Environment	Cognitive Process Dimensions (Anderson & Krathwohl, 2001)
Planned for	Concept building of NoS	Student-centered	High
Instructional implication	Transfer activity and NoS	learning Teacher-centered	Low

The same study identified **two types of ER**: student-centered and teacher-centered perspectives. The findings indicate that definitions aligned with a student-centered perspective (Type 1) more accurately reflect the initial intent of ER, which is to foster a critical understanding of NoS,

thereby contributing to the development of scientific literacy. Type 1 definitions were found to provide a more comprehensive account of ER, emphasizing higher cognitive process dimensions as outlined by Anderson and Krathwohl (2001) compared to those definitions with a teacher-centered (Type 2) perspective on ER (Figure 1).

Figure 1

The Two Types of ER: Student-centered and Teacher-centered

Type of ER	Meaning of Explicit	Meaning of Reflection	Cognitive Process Dimensions (Anderson and Krathwohl, 2001)
Type 1: Student-centered	Planned	Transfer learning activity between NoS and	Higher cognitive process dimensions
Type 2: Teacher-centered	Instructional implications	Transfer learning activity between NoS and	Lower cognitive process dimensions

Note. Both types of ER are characterized by three analytical themes – Meaning of Explicit, Meaning of Reflection and Cognitive Process Dimensions. This table is the synthesized version based on Boven et al. (2025).

NoS Questioning Approach

In the realm of science education research, the use of different types of NoS questions has garnered attention as a means to foster ER. Scholars like Kruse et al. (2020) and Voss et al. (2022) have explored the impact of question types on student thinking about NoS.

In the study by Kruse et al. (2020), four historical short stories were presented to 6th-grade students, accompanied by different NoS questions. The question types included: general reflection questions, general NoS questions, specific NoS questions targeting particular NoS ideas, and specific NoS questions with additional preamble (Table 2). The findings revealed that students tended to address more NoS ideas when asked specific questions with or without a preamble. In contrast, a significant decrease in the number of NoS ideas addressed was observed for general NoS questions, and students rarely addressed NoS ideas when asked general reflective questions. The study concluded that, therefore, specific NoS questions, with or without preamble, are more effective in drawing students' attention to a wide variety of accurate NoS ideas compared to more general questioning approaches.

Similarly, Voss et al. (2022) explored the nature of student responses to different questions. They distinguished general reflection questions and NoS-specific questions, which were further categorized as evaluative, convergent, and divergent questions (Table 2). Their study collected data through writing, and students were presented with a story combined with varying question types. The

findings indicated that the type of question influenced student responses significantly. Much like the findings of Kruse et al. (2020), responses to the general reflection questions were largely unrelated to NoS, indicating their limited effectiveness in teaching NoS concepts. Evaluative questions tended to elicit normative or, according to the authors, misconception responses, while divergent questions allowed for a wider range of views, including some misconceptions (from a consensus viewpoint, see consensus vs non-consensus view, later in this article). Convergent questions, biased towards consensus NoS views, often resulted in normative responses.

In conclusion, the findings from both Kruse et al. (2020) and Voss et al. (2022) suggest that specific NoS questions, presented in a divergent or convergent manner, are preferred for NoS education (Table 1). Divergent questions encourage students to explore a broader range of NoS perspectives and may be favored by those who do not align with the consensus view. In contrast, convergent questions guide students toward a consensus view understanding of NoS.

Other types of NoS questions appear to be less effective. For instance, while general NoS questions may serve as informal assessments of student thinking and initiate NoS discussions, they are less effective in promoting deeper engagement with NoS concepts (Kruse et al., 2020). Furthermore, evaluative questions, although suitable for assessment purposes, do not seem to stimulate significant development of NoS ideas among students (Voss et al., 2022).

Importantly, the two studies both emphasized the limited effectiveness of general reflection questions with no clear link to NoS in fostering meaningful NoS discussions in the classroom. Therefore, their use should be avoided or minimized.

Table 2

Summary of the Types of Questions to Evoke Explicit Reflection in NoS Education as Categorized by Kruse et al. (20) and Voss et al. (2022)

Author	Type of Question	Example	Result
Kruse et al. (2020) and Voss et al. (2022)	General reflection questions	“Based on what you just read, what do you notice or want to remember?”	Rarely/ No NoS ideas addressed
Kruse et al. (2020)	General NoS questions	“How is doing science like composing music?”	Low amount of NoS ideas addressed
	Specific NoS questions	“How does the need to make sense of data account for disagreements among scientists and the inventive character of science?”	High amount of NoS ideas addressed
	Specific NoS questions + additional preamble	“Note that the data is not telling the scientists what to think. Instead, scientists have to develop ideas that will account for the data... How does the need to make sense of data account for disagreements among scientists and the inventive character of science?”	High amount of NoS ideas addressed
Voss et al. (2022)	Evaluative questions	“Do you think that scientific knowledge involves only observable facts? Do you think that scientists use their inferences along with their observations?”	Normative or misconception responses
	Divergent questions	“How were we being like scientists in what we just did?”	Wider range of NoS views, some misconceptions
	Convergent questions	“Why do you think being creative is important for science?”	Normative, consensus view responses

Conceptualization of NoS

Consensus Versus Non-consensus View

One of the driving factors behind the discussion of NoS in science education has been the recognition of misconceptions about NoS held by both students and teachers (Cofré et al., 2019; Lederman, 1992). The consensus view of NoS has emerged as a valuable tool to list, clarify and possibly address these alternative conceptions. The consensus view gives a simplified image of NoS for educational purposes, it serves as a means to communicate accurate NoS ideas to K-12 students (Abd-El-Khalick et al., 1998). The consensus view entails a set of key aspects that have achieved widespread agreement among scientists and the academic community providing a foundation for NoS instruction in schools offering clarity and simplicity in addressing NoS (Kruse et al., 2020).

The seven key aspects identified within the consensus view include (Abd-El-Khalick and Lederman, 2000):

- 1) **Science is Empirical:** This aspect highlights the foundational role of empirical evidence in scientific knowledge. It underscores the principle that scientific claims should be grounded in observable phenomena.
- 2) **Science is Creative and Imaginative:** It recognizes the creative nature of scientific inquiry, emphasizing that scientific discoveries often involve innovative thinking and imaginative problem-solving.
- 3) **Science is Theory-Laden:** This aspect acknowledges that scientific knowledge is laden with theoretical constructs and paradigms, which guide scientific investigations and interpretations.
- 4) **Science is Embedded in Society and Culture:** It emphasizes that scientific knowledge is influenced by social, cultural, and historical contexts. Science is not isolated but interconnected with the broader societal and cultural landscape.
- 5) **Science is Tentative:** This aspect underscores the provisional and dynamic nature of scientific knowledge. It highlights that scientific theories and models are subject to revision as new evidence emerges.
- 6) **No One Method to Science:** It acknowledges that there isn't a single universal scientific method. Science employs a variety of methods and approaches to investigate the natural world.
- 7) **Differences between Theories and Laws:** It differentiates between scientific theories and laws, emphasizing that these serve distinct purposes within the scientific enterprise.

These seven aspects are often referred to as the *Lederman 7*. Notably, the name, the Lederman 7, was given by other researchers as an attribution to Norman G. Lederman's importance in the field, while Lederman himself referred to the framework as *Aspects of NoS*. Many subsequent NoS frameworks have drawn inspiration from or built upon the Lederman 7.

A substantial body of scholars endorse the consensus view (Abd-El-Khalick, 2001; Akerson et al., 2007; Bell et al., 2011; Hanuscin, 2013; Khishfe, 2015; McComas, 2020; Schwartz & Crawford, 2004) with notable academics, such as Norman Lederman, Fouad Abd-El-Khalick, and William McComas, offering their distinctive interpretations of the consensus view. Moreover, the consensus view has left an indelible mark on science education standards, finding adherence in respected institutions from the United States of America like the National Science Teaching Association (NSTA, 2020) and the former National Research Council (NRC, 2000), now known as the Next Generation Science Standards (NGSS, 2013).

One of the newest approaches to the consensus view comes from McComas (2020). McComas' NoS ideas reflect many of the recommendations widely offered but is unique in that related NoS elements are clustered into three bigger domains labeled *the tools and products of science*, *the human elements of science*, and *science knowledge and its limits*. Within each domain there are three major sub-elements or key NoS aspects. They are connected as follows:

- **Tools and products of science:** *evidence is vital, laws and theories are related but distinct and shared methods;*
- **The human elements of science:** *creativity is everywhere, subjectivity and bias are present, interaction with society and culture;*
- **Science knowledge and its limits:** *distinction from engineering and technology, tentativeness, durability and self-correction and science has limits.*

The consensus view of NoS offers an accessible entry point for teaching NoS in K-12 settings. However, it is not without criticisms. While the consensus view simplifies NoS for pedagogical purposes, it faces criticism for its oversimplification and lack of nuance. Critics argue that it overlooks

the differences between scientific disciplines and omits many intricacies of the scientific process (Allchin, 2017; Matthews, 2012).

Furthermore, proponents of the consensus view have been criticized of promoting an essentialist approach to NoS, which oversimplifies the rich diversity of scientific practices and worldviews across various disciplines (Wan et al., 2013). According to Wan et al. (2013) it provides a framework through which NoS is described monolithically as it 'is' or 'ought' to be. This can lead to students forming new stereotypes or alternative conceptions that may hinder a more nuanced understanding of NoS.

Given the critiques on the consensus view, researchers have turned their attention to alternative perspectives, distinct from the consensus paradigm. These **non-consensus approaches** include, among others, Clough's question approach (2007), the epistemic and non-epistemic approach of García-Carmona and Acevedo-Díaz (2018) and the family resemblance approach (FRA) (Dagher & Erduran, 2016; Erduran & Dagher, 2014; Irzik & Nola, 2011, 2014).

Clough's NoS questions (2007) aim to address the distortion of NoS tenets, encouraging their investigation rather than mere instruction in science classrooms. NoS issues are presented as questions to avoid the notion of a final form of science. Some of his thought-provoking questions include: "In what sense is scientific knowledge tentative? In what sense is it durable?", "How does private science differ from public science? In what ways are they similar?", and "In what sense is scientific knowledge invented? In what sense is it discovered?" (p. 33).

The epistemic and non-epistemic aspects of NoS framework, proposed by García-Carmona, and Acevedo-Díaz (2018), offer a balanced integration of epistemic and non-epistemic elements drawn from an exhaustive review of literature on the philosophy, sociology, history of science, and science education related to NoS. The epistemic factor is categorized into *nature of the scientific process* and *nature of scientific knowledge*, while the non-epistemic factors are further divided into *factors internal to the scientific community* and *factors external to the scientific community*. Within these categories, they propose many NoS themes to be discussed such as *the role of research questions*, *gender influence* and *role of media in science dissemination*.

Irzik and Nola (2011, 2014) introduced the **family resemblance approach** (FRA) to offer a more nuanced perspective on understanding NoS. In their framework, science is viewed as a complex system encompassing both cognitive-epistemic and social-institutional elements. They likened various scientific disciplines to a family, highlighting shared characteristics while also acknowledging unique traits within each discipline (Kaya et al., 2019, p. 24). Instead of presenting NoS as a set of fixed statements, the FRA provides a system of categories meant to be explored within specific scientific domains and historical contexts. According to the authors, the FRA promotes a dynamic, creative, and adaptable understanding of NoS. However, the FRA is also not without flaws as it presents challenges for implementation in educational settings, especially considering that science teachers already find it challenging to implement the consensus view of NoS (Bugingo et al., 2022).

Open Versus Closed NoS Approaches

To categorize NoS frameworks, closed approaches can be distinguished from open approaches. According to Irzik and Nola (2011) the closedness of NoS comes in three forms:

Firstly, the conceptualization of NoS presents a narrow perspective, intentionally omitting aspects that lack consensus to enhance clarity. However, this selective approach can render NoS topics undiscussable. For instance, asserting, there is no single scientific method, fails to acknowledge the existence of overarching methodologies, like the hypothetico-deductive method, and general methodological principles that guide scientific practices. Neglecting such foundational principles raises questions about science's self-corrective nature in the absence of methodological rules. Furthermore,

excluding scientific inquiry is done in an artificial way, leaving out aspects of scientific inquiry means leaving out important aspects of what makes science, science, which is in fact, NoS.

Secondly, the portrayal of NoS conveys a monolithic-view of science, disregarding the inherent disparities among various scientific disciplines and projecting an impression of rigidity and timelessness.

Finally, the conceptualization of NoS lacks a comprehensive and systematic unity. The interconnections among NoS components are not clearly delineated, leading to noticeable tensions. For instance, when recognizing that science is socially and culturally embedded, a challenge arises regarding how it manages to produce universally valid knowledge applicable across diverse cultures and societies. In contrast, according to Irzik and Nola (2011) more open approaches to NoS exemplify a dynamic, creative, and open-ended NoS.

This Study

In this study, we investigate the multifaceted meanings of ER in the context of NoS education. We address two research questions:

RQ 1: How does the type of ER (student-centered or teacher-centered) relate to both the questioning approach aimed at achieving ER and the conceptualization of NoS in academic NoS literature?

RQ2: How does the conceptualization of NoS (open, mixed, closed) relate to both the four analytical themes of ER and the questioning approach aimed at achieving ER in academic NoS literature?

Methodology

To expand upon the systematic literature review of Boven et al. (2025), we employed the same corpus of literature which was collected through the PRISMA method (Page et al., 2021) and included 60 articles.

We applied the holistic analysis approach of Lieblich et al. (1998) to conduct a thorough examination of the various interpretations of ER within the context of the articles themselves. Holistic analysis entails a meticulous exploration of recurring themes across different articles. This method emphasizes that each ER definition should not be examined in isolation but rather considered in conjunction with the entirety of the article, contributing to a more profound and nuanced exploration of the subject matter at hand. We utilized the holistic analysis approach to identify all the essential elements within the selected articles to address our research questions (Lieblich et al., 1998), including:

- 1) Identifying and analyzing all the questions employed inside the articles used to achieve ER about NoS
- 2) Identifying and analyzing all NoS frameworks used inside the articles to understand how each article conceptualizes NoS

NoS Questioning Approach

As a key part of our methodology, we catalogued all questions in the articles that were used to elicit ER about NoS. To achieve this, we read all 60 articles in full to identify every relevant question. In our analysis, we considered not only the questions explicitly stated in each article but also those that were mentioned indirectly or implied by the authors.

As an illustrative example of this approach: Akerson et al. (2000) use in their article a total of five questions to elicit ER. Additionally, the authors integrate NoS activities introduced by Lederman and Abd-El-Khalick (1998) in the publication: *Avoiding De-Nature Science: Activities that Promote Understanding of the NoS*, which incorporate 17 questions aimed at eliciting ER. Therefore, for the article of Akerson et al. (2000), we consider both their own five questions and the 17 questions of Lederman and Abd-El-Khalick (1998), as part of their questioning approach, resulting in a combined total of 22 questions.

We considered a single question as one unit when it possessed the capacity to function independently. To elucidate this, we refer to an example from the work of Witucki et al. (2023), who proposed the following question for eliciting ER: “Do scientists use their imagination/creativity? If so, then how? If not, then why not?” (p. 27). In our analysis, this question was regarded as a singular unit, even though it encompasses three distinct components. It is worth noting that the components “*If so, then how?*” and “*If not, then why not?*” lack independent significance and meaning in isolation; hence, they were treated as integral constituents of the overarching question.

To facilitate a structured and meaningful categorization of the identified questions, we utilized the categorization frameworks provided by Kruse et al. (2020) and Voss et al. (2022) as outlined in Table 2 in our theoretical framework. This systematic categorization process enabled us to analyze the questioning approach of the articles in a comprehensive and organized manner, in alignment with the goals of our research.

Conceptualization of NoS: Expert Content Validation

In this study, the categorization of NoS frameworks is aimed at providing a comprehensive understanding of the diverse perspectives within the NoS field. We conducted our analysis using the NoS frameworks present within the 60 articles. Frameworks were identified through a comprehensive read-through of all the articles, with articles lacking explicit mention of a framework excluded from the analysis. However, special consideration was given to one article authored by Duschl and Grandy (2013), titled “Two Views About Explicitly Teaching Nature of Science”, which presented two distinct NoS frameworks. Within this article, the authors not only provided two discrete perspectives on ER but also delineated contrasting outlooks regarding the conceptualization of NoS. These dual-NoS conceptualizations corresponded to two separate NoS frameworks. Consequently, we treated these dual conceptualizations of NoS, as elucidated in Duschl and Grandy's article, as distinct entities within our analytical framework.

After all the frameworks were identified, we categorized them into three distinct groups - open, mixed, and closed towards NoS – following the definition of Irzik and Nola (2011) for the concepts of *closedness* and *openness*. Closed frameworks reflect a narrow perspective on NoS, characterized by a monolithic-view of science and a lack of comprehensive and systematic unity. Open frameworks, on the other hand, demonstrate a dynamic, creative, and open-ended approach to NoS. Mixed frameworks incorporate elements from both perspectives.

Expert Selection

We selected four experts specializing in research on NoS education. Each expert was chosen for their expertise in the field, with one specializing in science teacher education, another currently pursuing a doctoral dissertation on NoS education, a third engaged in post-doctoral research on science communication, and the fourth serving as a lecturer in philosophy and science education. To ensure impartiality in the categorization of the frameworks, none of the selected experts had

participated in the creation of any of the frameworks under assessment. Additionally, two of the experts were external to the study, while the other two were authors of the study.

Expert Content Validation of NoS Frameworks

To ensure an unbiased assessment, the four NoS experts independently evaluated the NoS frameworks. The evaluation process was carried out in a blinded manner. This means that the experts were provided with excerpts from the framework descriptions with all identifying information redacted. This approach guaranteed impartiality in the evaluation, as the experts were unaware of the specific framework names and authors.

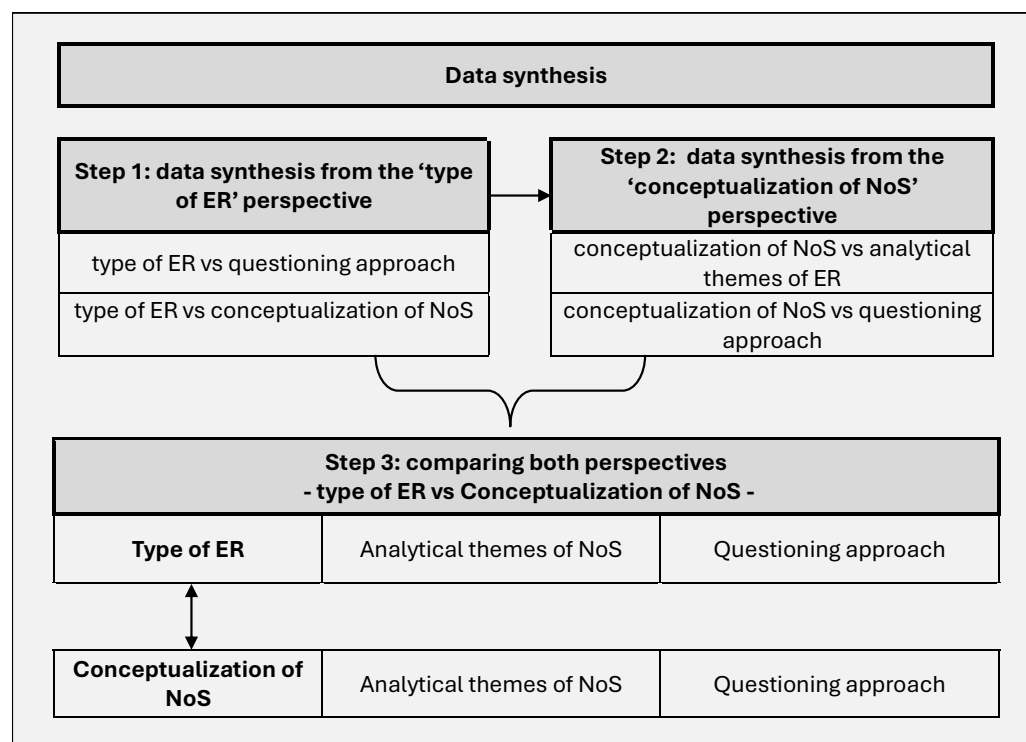
Initially, the evaluations resulted in minor discrepancies ($\kappa=.85$) in the categorizations of the frameworks. However, through rigorous discussions and deliberations, a consensus was reached about the categorization among the experts. The consensus-building process was instrumental in ensuring that the final categorizations accurately reflected the experts' collective assessment.

Data Synthesis

After collecting and categorizing the relevant data, we synthesized the findings to identify patterns, connections, and potential disparities. We followed a three-step approach shown in Figure 2.

Figure 2

The Three-step Approach for the Data Synthesis



In step one, we looked at the data from the *type of ER* perspective based on the framework provided by Boven et al. (2025) (Figure 1), which includes student-centered and teacher-centered ER, along with their respective characteristics. This step involved two sub-steps. First, we compared the type of ER and the questioning approach by examining the variety of question types used to stimulate ER (Table 2.) and comparing them across articles that align with either student-centered (type 1) or teacher-centered (Type 2) definitions of ER. Second, we compared the type of ER (student- or teacher-centered) with the conceptualization of NoS as open, mixed, or closed. This conceptualization of NoS was determined in the expert content validation.

In step two, we examined the data through the lens of *the conceptualization of NoS* (open, mixed, closed). This step comprised two sub-steps. Firstly, we compared the conceptualization of NoS in articles with the analytical themes used to define ER based on the framework provided by (Boven et al., 2025) (Figure 1). Secondly, we compared the conceptualization of NoS in articles with the questioning approach, scrutinizing the variety of question types employed to stimulate ER on NoS (Table 2) across articles aligning with open, mixed, or closed approaches to conceptualizing NoS. In the final step, step three, we conducted a comparative analysis of the synthesized data from both perspectives: *type of ER* and *conceptualization of NoS*, seeking alignment or discrepancies in patterns among both perspectives.

Results

NoS Questioning Approach

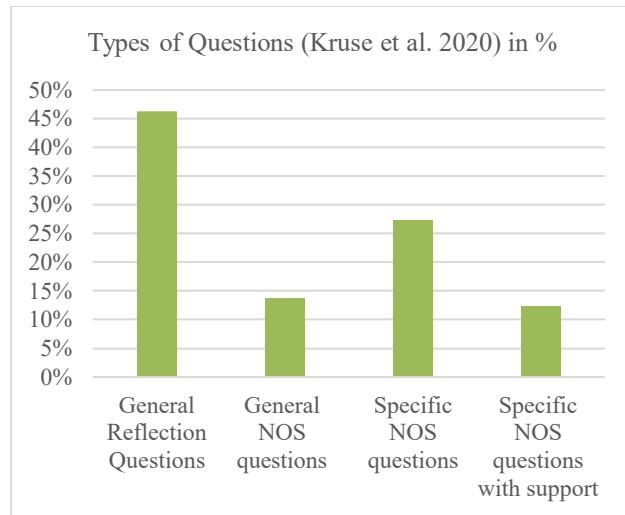
Within the 60 articles related to NoS education, 47 mentioned at least one question for encouraging ER on NoS. In total 589 questions were identified. Kruse et al. (2020) and Voss et al. (2022) have one category in common, the non-NoS questions named *general reflection questions*. We found that 277 questions (47%) fell under the classification of general reflection questions.

Additionally, using Kruse et al.'s definitions, we identified 82 questions (14%) as general NoS questions, 158 questions (27%) as specific NoS questions, and 71 questions (12%) as specific NoS questions with supportive information (preamble) (Figure 3).

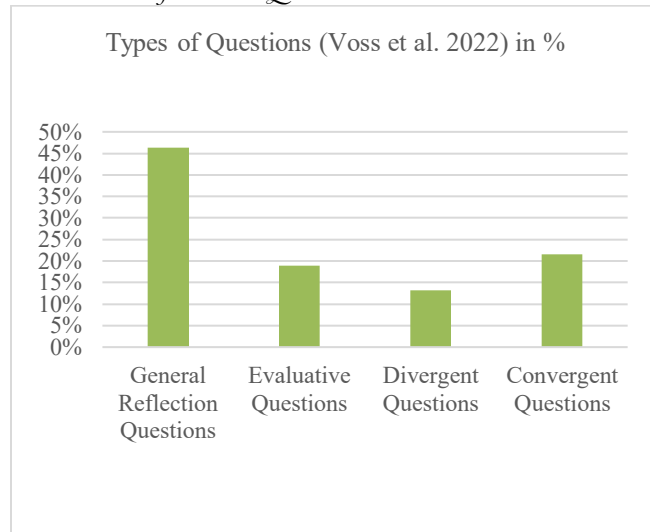
Moreover, applying the categorization by Voss et al. (2022), we determined that 112 questions (19%) were evaluative NoS questions, 77 questions (13%) were divergent NoS questions, and 123 questions (21%) were convergent NoS questions (Figure 4).

Figure 3

Distribution of the 589 Questions Used in the 47 Articles Following Kruse et al.'s Categorization (2020)

**Figure 4**

Distribution of the 589 Questions Used in the 47 Articles Following Voss et al.'s Categorization (2022)



Conceptualization of NoS

Among the 60 articles included in this systematic review, we identified eight distinct frameworks for understanding NoS. These frameworks ranged from being developed in 2000 to 2020. Chronologically these frameworks were: *The Lederman 7* (2000), *NRC* (2000), *Clough's questions* (2007), *FRA* (2011), *NGSS* (2013), *Epistemic and non-epistemic NoS* (2018), *NSTA* (2020) and *McComas' NoS ideas* (2020) (Table 3). Five of these frameworks are recognized as NoS consensus view frameworks, namely, *The Lederman 7*, *NSTA*, *McComas' NoS ideas*, *NRC*, and *NGSS*. The remaining three frameworks, *Clough's questions*, *FRA* and *Epistemic and non-epistemic NoS*, are recognized as non-consensus view frameworks (Abd-El-Khalick & Lederman, 2000; Clough, 2007; Clough & Olson,

2008; García-Carmona & Acevedo-Díaz, 2018; Irzik & Nola, 2011; McComas, 2020; NGSS, 2013; NRC, 2000; NSTA, 2020).

Table 3

The Eight Identified NoS Frameworks

NoS framework	Number of articles
NoS consensus view framework	
The Lederman 7 (Abd-El-Khalick and Lederman, 2000)	28
NSTA (NSTA, 2020)	8
McComas' NoS ideas (McComas, 2020)	7
NRC (NRC, 2000)	3
NGSS (NGSS, 2013)	2
Total	48
NoS non-consensus view framework	
Clough's questions (Clough, 2007)	3
FRA (Irizik and Nola, 2011)	2
Epistemic and non-epistemic NoS (García-Carmona and Acevedo-Díaz, 2018)	2
Total	7
No framework mentioned	6

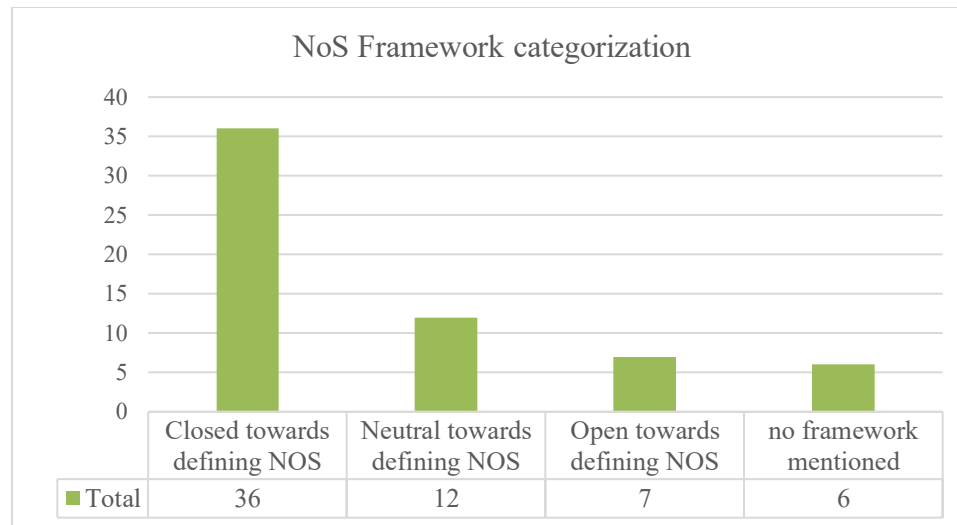
Among the 60 selected articles, The Lederman 7 emerged as the most frequently used NoS framework (46%), while NGSS (3%), FRA (3%) and Epistemic and non-epistemic NoS (3%) were the least commonly employed. Additionally, six articles did not mention a specific NoS framework. It is to be observed that the NoS consensus view is the most used approach in research on ER in NoS education.

In the expert content validation process of classifying frameworks into *closed*, *mixed*, and *open* categories for the conceptualization of NoS, both The Lederman 7 and the NSTA NoS frameworks were categorized as closed. This category, comprising a total of 36 articles, emerged as the most prevalent within the literature included in this study. The mixed category encompassed the NRC, 'NGSS', and 'McComas' ideas' NoS frameworks, constituting a total of 12 articles. Conversely, the open category, which included Clough's questions, FRA, and the Epistemic and non-epistemic NoS frameworks, was the least utilized, featuring only seven articles. Figure 5 provides an overview of the distribution of articles across these different categories.

The analysis indicates that a significant portion of the articles defining ER for NoS education predominantly utilized NoS frameworks with relatively closed definitions for NoS, leaving less space for complexity and context.

Figure 5

Distribution of the NoS Frameworks over the Three Categories -Closed, Mixed, Open- towards NoS, as Defined by the Four NoS Experts



Data Synthesis

The data synthesis presents an overview of (1) the types of questions used to elicit ER on NoS and (2) how NoS was conceptualized in each article, based on expert content analysis.

A total of 589 questions were analyzed, drawn from the 47 articles that included at least one question (13 articles included no questions). Each question was first categorized as either NoS-related (i.e. addressing General or Specific NoS content) or non-NoS-related (i.e. General Reflection, with no explicit reference to NoS). This distinction is mutually exclusive: questions were either classified as NoS-related or not. For NoS-related questions, a second layer of classification was applied: each question was further categorized as Evaluative, Divergent, or Convergent, with only one of these three applied per question. For definitions of each question type and examples, see Table 2, which outlines the coding framework used to guide the categorization process.

The second part of Table 4 reports how NoS frameworks were interpreted within each article, categorized as Closed, Mixed, or Open, based on expert content analysis. Six articles did not reference a NoS framework.

Table 4*Summary of the Findings of the Holistic Analysis*

Questioning approach	% of articles ^a
(Kruse et al, 2020; Voss et al, 2022)	
General Reflection	47
(Kruse et al, 2020)	
General NoS Question	14
Specific NoS Question	39
(Voss et al, 2022)	
Evaluative Questions	19
Convergent Question	21
Divergent Question	13
Conceptualization of NoS (Expert Content Analysis)	% of articles ^b
Closed	65
Mixed	22
Open	13

^a The percentage is based on all articles that included questions. 13 articles did not include any questions and are therefore not included in this summary. The overall total of questions included in all articles was 589 questions.

^b The percentage is based on all articles that included a NoS framework. As mentioned earlier, 6 articles did not include any NoS framework and are therefore not included in this summary

RQ1.1: The Type of ER vs the Questioning Approach

To address the initial aspect of research question one, we analyzed each of the 60 articles to examine the relation between the type of ER, whether it was student- (Type 1) or teacher-centered (Type 2), with the questioning approach employed to evoke ER on NoS. We observed notable

differences in the utilization of questions between articles with Type 1: student-centered (n=26) and Type 2: teacher-centered definitions of ER (n=35). Articles adhering to Type 1 employed a total of 305 questions, of which 181 (59%) were related to NoS. On average, these articles contained twelve questions (SD=8,77), with seven focusing on NoS. In contrast, articles with a Type 2 definition of ER featured 267 questions in total, with 126 (47%) of them addressing NoS. On average, these articles contained eight questions (SD=7,67), with four centered on NoS, which was a significantly lower proportion compared to the articles containing a Type 1 approach towards defining ER ($p=0.0043$).

When we specifically analyzed the NoS-related questions in articles with a Type 1, student-centered approach, we observed that 75% of them were specific NoS questions, targeting particular aspects of NoS (Table 5). For instance, questions such as *"Do you think scientists need creativity?"* were prevalent. The remaining 25% consisted of general NoS questions, such as *"How were you acting like a scientist today?"*. This categorization was based on the criteria outlined by Kruse et al. (2020). Utilizing the framework proposed by Voss et al. (2022), we further categorized the NoS-related questions. Articles with a Type 1 approach to ER predominantly featured convergent NoS questions (45%), followed by evaluative (31%) and divergent (24%) NoS questions.

Considering articles adopting a Type 2, teacher-centered, approach to ER, the majority (71%) of NoS-related questions were specific in nature, primarily targeting distinct NoS aspects. The remaining 29% encompassed general NoS questions, as per Kruse et al.'s criteria. When employing Voss et al.'s framework, these articles mainly included evaluative NoS questions (41%), followed by convergent (32%) and divergent (27%) NoS questions. The observed variations in the categorization of NoS questions between the two types of ER didn't differ significantly.

Table 5

Summary of the Questioning approach Categorized According to the Two Types of ER

Questioning approach	Type 1: Student-centered		Type 2: Teacher-centered	
	n	%	n	%
(Kruse et al, 2020)				
General NoS Question	45	25	37	29
Specific NoS Question	136	75	89	71
Total	181	100	126	100
(Voss et al, 2022)				
Evaluative Questions	56	31	52	41
Convergent Question	81	45	40	32
Divergent Questions	44	24	34	27
Total	181	100	126	100

Note. A total of 26 articles were related to Type 1 and a total of 35 articles were related to Type 2. Definition for ER Based on (Boven et al., 2025).

RQ1.2: The Type of ER vs the Conceptualization of NoS

To address the second aspect of research question one, we conducted a comparison for each of the 60 articles. This comparison involved examining the type of ER, whether it was student- (Type 1) or teacher-centered (Type 2), with the way NoS was conceptualized in the article (Open, Mixed, Closed) (Table 6). The predominance of NoS frameworks categorized as *closed towards defining NoS* is a notable trend, and both student- and teacher-centered definitions of ER predominantly align with frameworks classified as such. In articles where a student-centered definition of NoS was employed, the alignment with the closed approach was observed 54% of the time. For articles with a teacher-centered NoS definition, the alignment with the closed approach occurred in 63% of the cases.

Table 6

Summary of the Findings of the Conceptualization of NoS Related to the Learning Environment

Type of ER	NoS conceptualization			Did not specify a NoS framework
	Open towards defining NoS	Mixed towards defining NoS	Closed towards defining NoS	
Type 1: Student-centered	19%	19%	54%	8%
Type 2: Teacher-centered	6%	20%	63%	11%

R.Q.2: The Conceptualization of NoS vs the Four Analytical Themes of ER and the Questioning Approach

To address research question two, we analyzed each of the 60 articles to examine the relation between the conceptualization of NoS, whether it was open, mixed or closed with both the four analytical themes for ER (Table 1) and the questioning approach employed to evoke ER on NoS. We observed notable differences (Table 7). In the articles with a framework that is more open towards the conceptualization of NoS (n=7), ER is predominantly understood as a planned learning activity (100%) in which a transfer is made to NoS elements (87%), lower cognitive process dimensions are emphasized (71%), and the learning environment is written in a student-centered way (71%). The questioning approach to evoke ER on NoS involves an average of 13 questions, mostly specific (75%), convergent NoS questions.

In the articles with a framework that is more mixed towards the conceptualization of NoS (n=12), ER is largely understood as a planned learning activity (67%) in which a transfer is made to NoS elements (58%), higher cognitive process dimensions are emphasized (58%), and the learning environment is written in a teacher-centered way (58%). The questioning approach includes an average of eight questions, mostly specific (75%), convergent NoS questions.

In the articles with a framework that is more closed towards the conceptualization of NoS (n=36), ER is largely understood as an instructed learning activity (58%) in which a transfer is made to NoS elements (53%), lower cognitive process dimensions are emphasized (72%), and the learning

environment is written in a teacher-centered way (61%). The questioning approach includes an average of nine questions, mostly general reflection questions (57%).

Table 7

Summary of the Relationship Between the Conceptualization of NoS, the Four Analytical Themes of ER and the Questioning Approach

Conceptualization of NoS ^a	Analytical themes of ER (Boven et al., 2025)				Questioning Approach
	Meaning of Explicit	Meaning of Reflection	Cognitive process dimensions	Learning Environment	
Open (n=7)	Planned (100%)	Transfer between learning activity and NoS (86%)	Lower cognitive process dimensions (71%)	Student- centered (71%)	Avg. 13 questions, mostly specific (75%) convergent NoS questions
Mixed (n=12)	Planned (67%)	Transfer between learning activity and NoS (58%)	Higher cognitive process dimensions (58%)	Teacher- centered (58%)	Avg. 8 questions, mostly specific (71%) convergent NoS questions
Closed (n=36)	Instructional implications (58%)	Transfer between learning activity and NoS (53%)	Lower cognitive process dimensions (72%)	Teacher- centered (61%)	Avg. 9 questions, mostly general reflection questions (57%)

^a Only articles with a conceptualization of NoS (n=55) are included in this overview.

Patterns between articles: the type of ER and the conceptualization of NoS

In the last step of this study, we conducted a comparative analysis of the synthesized data from both perspectives: *type of ER* and *conceptualization of NoS*, seeking alignment or discrepancies in patterns among both perspectives. The findings show that articles adhering to a more closed approach to conceptualizing NoS demonstrated similarities with articles adopting a teacher-centered perspective (Type 2) in defining ER (Figure 6).

Figure 6

Comparison of the Articles Adhering to Type 2 ER and a Closed Conceptualization of NoS

Type of ER	→	Meaning Explicit	of	Meaning Reflection	of	Cognitive Process Dimensions	Questioning Approach
Type 2: Teacher-centered	→	Instructional implications		Transfer between learning activity and NoS		Lower cognitive process dimensions	8 questions on average, mostly general reflection questions not related to NoS
Conceptualization of NoS	→	Meaning Explicit	of	Meaning Reflection	of	Cognitive Process Dimensions	Questioning Approach
Closed	→	Instructional implications		Transfer between learning activity and NoS		Lower cognitive process dimensions	9 questions on average, mostly general reflection questions not related to NoS

Additionally, articles adopting a mixed stance on conceptualizing NoS exhibited patterns akin to those of articles employing a student-centered approach to define ER (Figure 7).

Figure 7

Comparison of the Articles Adhering to Type 1 ER and a Mixed Conceptualization of NoS

Type of ER	→	Meaning Explicit	of	Meaning Reflection	of	Cognitive Process Dimensions	Questioning Approach
Type 1: Student-Centered	→	Planned		Transfer between learning activity and NoS		Higher cognitive process dimensions	10 questions on average, mostly specific convergent NoS questions
Conceptualization of NoS	→	Meaning Explicit	of	Meaning Reflection	of	Cognitive Process Dimensions	Questioning Approach
Mixed	→	Planned		Transfer between learning activity and NoS		Higher cognitive process dimensions	8 questions on average, mostly specific convergent NoS questions

Lastly, when examining the patterns within articles employing a more open approach to conceptualizing NoS, we observed a closer alignment with articles that employed a student-centered approach to define ER. Nevertheless, it is worth noting that these articles often framed their ER definitions in terms of lower cognitive process dimensions, a characteristic more commonly associated with teacher-centered definitions and not typical of student-centered ones (Figure 8).

Figure 8

Comparison of the Articles Adhering to Type 1 ER and an Open Conceptualization of NoS

Type of ER	Meaning Explicit	Meaning Reflection	Cognitive Process Dimensions	Questioning Approach
Type 1: Student-Centered	Planned	Transfer between learning activity and NoS	Higher cognitive process dimensions	10 questions on average, mostly specific convergent NoS questions
Conceptualization of NoS	Meaning Explicit	Meaning Reflection	Cognitive Process Dimensions	Questioning Approach
Open	Planned	Transfer between learning activity and NoS	Lower cognitive process dimensions	13 questions on average, mostly specific convergent NoS questions

Discussion

In this section, we delve into the key findings of our study and discuss their implications within the context of ER in NoS educational literature.

NoS Questioning Approach

The findings of our study highlight the significance given to asking questions to evoke ER about NoS. When analyzing all 60 articles, only 13 articles did not mention any questions. Building on Kruse et al.'s (2020) research, our analysis categorized questions into three types: *General Reflection*, *General NoS question*, *Specific NoS Question*. The findings of our study revealed a prominent emphasis on general reflection questions such as, “*How did you develop this inquiry plan?*” (Zion et al., 2020). These questions, however, tend to convey NoS ideas implicitly rather than explicitly. It is crucial for future research in this area to align with the intended explicitness of ER by employing more specific NoS questions (Kruse et al., 2020). These specific NoS questions are according to (Voss et al., 2022) best asked in a convergent way to achieve consensus view answers from students (e.g. “*Why is well-established science knowledge often so durable and enduring?*” (Parrish et al., 2020)) or in a divergent way to achieve a wider range of NoS views (e.g. “*What makes a good scientist?*” (Dunlop and De Schrijver, 2020)). Such approaches hold promise for enhancing the effectiveness of NoS education and fostering a deeper understanding of NoS concepts among learners (Kruse et al., 2020; Voss et al., 2022). Only 34% of the questions analyzed were classified as either convergent (21%) or divergent (13%). Consequently, 66% of the

questions used across all articles were less effective in promoting deeper engagement with NoS concepts, as defined by Kruse et al. (2020) and Voss et al. (2022).

Conceptualization of NoS

Our systematic review identified eight distinct NoS frameworks, categorized into two groups: those aligning with the NoS consensus view and those not. The prevalence of articles adhering to the consensus view underscores its dominance in research, primarily utilizing widely accepted NoS principles.

Regarding the notion that consensus view frameworks are oversimplified, closed and rigid toward defining NoS (Allchin, 2011, 2017; Clough, 2007; Irzik and Nola, 2011, 2014; Matthews, 2012), our study partially supports this. The McComas NoS ideas, NRC, and NGSS frameworks fall under the ‘mixed towards defining NoS’ category, while the Lederman 7 and NSTA are categorized as *closed towards defining NoS*. None of the consensus view NoS frameworks were categorized as *open towards defining NoS*, therefore, offering partial confirmation.

This pattern implies that consensus-based frameworks, while providing structure and pedagogical clarity, may simultaneously constrain the complexity and diversity of scientific practices presented in classrooms. As such, there appears to be a trade-off between accessibility and epistemic richness, where pedagogical clarity may come at the expense of conceptual depth and inclusiveness. This systematic review also reveals that many articles on ER in NoS education predominantly employed NoS frameworks with relatively closed NoS definitions. This trend may prompt important discussions about how using different NoS frameworks affects the depth and scope of ER in NoS education.

These findings hold significant implications for researchers and educators in NoS education. Researchers should be aware of how selected NoS frameworks influence the interpretation and implementation of ER. Educators should consider these findings when designing NoS education curricula, acknowledging that *closed* frameworks dominate educational practice. However, the potential benefits of integrating *mixed* and *open* frameworks to foster nuanced discussions and understanding of NoS should not be underestimated.

Data Synthesis

RQ1.1: The Type of ER vs the Questioning Approach

The key findings from our analysis reinforce the notion proposed by Boven et al. (2025) that articles having student-centered definitions of ER (Type 1 ER) have distinct advantages over their teacher-centered (Type 2 ER) counterparts. Firstly, we observed that articles employing a student-centered definition of ER exhibited a propensity to ask a significantly higher number of questions aimed at promoting ER in the context of NoS. This quantitative difference in the use of questions underscores the greater emphasis placed on active engagement and reflective practices within the articles with a student-centered approach to ER (Type 1 ER). Secondly, our analysis revealed that articles embracing a student-centered definition of ER not only posed more questions but also asked more effective questions, in particular, focusing on specific convergent NoS questions (Kruse et al., 2020; Voss et al., 2022).

In contrast, articles that adhered to a teacher-centered definition of ER asked significantly fewer questions, with most being general reflection questions, which are, according to Kruse et al. (2020), less effective. The predominance of general reflection questions, which are not explicitly related to NoS, indicates a potential misalignment between the questions posed and the specific goals

of NoS education. This suggests that articles with teacher-centered definitions of ER may not effectively promote in-depth, NoS-focused reflection among students.

In sum, our findings provide the confirmation that supports the superiority of articles utilizing student-centered definitions of ER (Type 1 ER). The richer question-asking environment and the focus on specific, convergent NoS questions underscore the effectiveness of this approach in promoting ER about NoS.

RQ1.2: The Type of ER vs the Conceptualization of NoS

Our analysis of the relationship between the type of ER and the conceptualization of NoS in 60 articles revealed interesting insights. Contrary to our initial expectation, which posited that articles using student- versus teacher-centered definitions for ER might conceptualize NoS differently, we found that both types of ER predominantly align with *closed* frameworks for defining NoS.

Additionally, our analysis revealed that among student-centered articles, 38% adhered to mixed or open NoS frameworks, whereas only 26% of teacher-centered articles did so. This difference suggests that student-centered approaches may offer a slightly greater diversity in conceptualizing NoS compared to teacher-centered approaches.

These findings underscore the importance of critically evaluating the relationship between ER types and NoS conceptualizations. While the alignment between ER types and NoS conceptualization is not absolute, it does provide valuable insights into prevailing trends in NoS education literature.

R.Q.2: The Conceptualization of NoS vs the Four Analytical Themes of ER and the Questioning Approach

The findings from our analysis show that articles having an open or mixed approach to conceptualizing NoS have distinct advantages over their closed approach counterparts. Firstly, we observed that articles employing an open or mixed conceptualization of NoS exhibited a propensity to ask a significantly higher number of questions aimed at promoting ER in the context of NoS compared to the articles with a closed conceptualization of NoS ($p=0.0001$). This quantitative difference in the use of questions underscores the greater emphasis placed on active engagement and reflective practices within the articles with an open or mixed conceptualization of NoS. Secondly, our analysis revealed that articles embracing an open or mixed conceptualization of NoS not only posed more questions but also asked more effective questions, in particular, focusing on specific convergent NoS questions (Kruse et al., 2020; Voss et al., 2022). In contrast, articles that adhered to a closed conceptualization of NoS asked significantly fewer questions, with most being general reflection questions, which are, according to Kruse et al. (2020), less effective.

Moreover, articles with an open conceptualization of NoS predominantly defined ER in a student-centered manner, which aligns with the preferred approach. Conversely, articles with a mixed conceptualization of NoS tended to emphasize ER on higher cognitive process dimensions, offering a potential benefit in promoting deeper engagement with NoS concepts. In contrast, articles with a closed conceptualization of NoS often adopted a less preferred approach, defining ER in a teacher-centered manner and focusing on lower cognitive process dimensions.

In conclusion, our analysis highlights the advantages of articles with an open or mixed approach to conceptualizing NoS over their closed approach counterparts.

Patterns Between Articles: the Type of ER and the Conceptualization of NoS

The comparisons drawn between our findings on *the type of ER* and *the conceptualization of NoS* reveal a compelling interplay between both. These insights help us delve into the nuanced dynamics that shape NoS education and encourage further exploration of their implications for both science education and research.

On the one hand, we observe an alignment between more closed NoS frameworks and teacher-centered ER definitions. This suggests that articles embracing established and conventional NoS tenets often favor a teacher-centered approach to ER. This alignment emphasizes the strong connection between traditional NoS conceptualizations and pedagogical practices that emphasize the role of the teacher in guiding students' reflection on NoS. This tendency may be rooted in the notion that teacher-centered approaches are generally seen as more prescriptive and didactic, aligning with more traditional and restrictive views of NoS.

On the other hand, articles adopting a mixed or open stance on NoS tend to align more with articles that have a student-centered perspective on ER. This suggests that these open and mixed frameworks, with their dynamic and more flexible NoS conceptualizations, resonate with the principles of student-centered ER. This alignment emphasizes the strong connection between innovative, open NoS conceptualizations and pedagogical practices that prioritize students.

These findings call for a shift in how researchers report about NoS interventions and instruction, away from rigid, transmissive models of science education and toward more student-centered, reflective approaches. In the hope that this encourages teachers, teacher educators, and curriculum developers to foster classroom environments that emphasize:

- Targeted NoS questioning that invites deep reflection, avoiding general reflection prompts;
- Open conceptualization of science, where science is not portrayed as a fixed body of facts but as a social, human, and collaborative enterprise;
- Student agency, enabling learners to grapple with the meaning, implications, and boundaries of science themselves, rather than receiving these ideas prepackaged.

The findings translate into clear guidance for the design of curricula and the formation of educational policy. Firstly, curriculum designers and educators should explicitly prioritize the use of Mixed and Open NoS frameworks to structure content, as these intrinsically harmonize with superior, student-centered pedagogical practices. Secondly, to translate the theoretical explicitness of ER into practice, instructional materials must feature a significantly higher frequency of specific NoS questions (e.g., Convergent or Divergent types) and actively minimize the use of non-NoS-related General Reflection questions. Finally, educational policies should critically re-evaluate existing standards that rely on purely Closed NoS conceptualizations. The data suggests that for NoS education to effectively evolve, the field must adopt frameworks that accommodate the nuance and complexity necessary to support true student-centered, reflective practice, thereby driving systemic educational improvements.

Limitations

While this study offers insights into the relationship between the conceptualization of ER, NoS frameworks, and questioning approaches, several limitations must be acknowledged.

First, although our analysis systematically identified and categorized the quantity and types of questions used to evoke ER, we did not assess the quality or classroom implementation of these questions. The presence of specific, divergent or convergent NoS questions in an article does not necessarily indicate their effective use in practice. It is unlikely that all questions asked by teachers during interventions or NoS lessons are reported in publications, given the dynamic and interactive nature of classroom discourse, which often includes follow-up questions, clarifications, extensions,

and spontaneous prompts. Without observational or empirical data on how these questions are posed, received, and discussed in actual educational settings, conclusions regarding their pedagogical effectiveness remain necessarily limited.

Second, our classification of ER definitions into *student-centered* and *teacher-centered* types, as well as the categorization of NoS frameworks as *open*, *mixed*, or *closed*, necessarily involved an element of interpretive judgment. Although we employed expert content validation to strengthen reliability, these categories are not always rigid or mutually exclusive. In several cases, articles demonstrated hybrid characteristics, making classification complex. This subjectivity may have influenced the patterns observed and calls for cautious interpretation of our typologies.

Third, this study does not fully consider the contextual diversity in which ER and NoS education occur. The selected articles span a range of countries, educational levels, and instructional settings, yet our analysis did not explicitly differentiate findings based on these variables. By not controlling for or analyzing these contextual factors, our synthesis may obscure important nuances and limit the generalizability of our conclusions across different educational environments.

Taken together, these limitations suggest that further empirical and context-sensitive investigations are necessary to deepen and validate these insights.

Future Research

Our study opens avenues for future research in the realm of NoS education and ER. There are four key areas that warrant further investigation.

Firstly, conducting a **comparative analysis** of NoS education approaches using closed, mixed and open NoS conceptualizations can shed light on the benefits and challenges associated with each. Examining the extent to which NoS frameworks influence ER practices and student engagement can deepen our understanding of effective pedagogical strategies.

Secondly, empirical **longitudinal studies** can offer insights into the long-term impact of various NoS conceptualizations and ER definitions on students' NoS understanding and their development as reflective thinkers. Tracking students over time and analyzing their progress can provide a comprehensive view of NoS education outcomes.

Thirdly, investigating the **evolution of NoS conceptualizations** and their implications for science education practices is a promising area of research. How and why NoS conceptualization has evolved, and how these changes have influenced ER approaches, is a topic that warrants exploration.

Finally, research examining the implications of NoS conceptualization and ER definitions for **educational policies and curricula** is essential. Understanding how these factors impact the design and implementation of science education programs can inform policy decisions and improve the quality of NoS education.

Conclusion

In this systematic review, we have delved into the intricate relationship between the conceptualization of NoS, the types of ER, and their implications for science education. Our study has unveiled critical insights into the way NoS education is approached and practiced, focusing on the significance of the questioning approach to evoke ER about NoS and the interplay between the type of ER, as student- or teacher-centered, and the conceptualization of NoS.

Notably, we observed that articles that embrace student-centered definitions of ER demonstrated some advantages over their teacher-centered counterparts. They asked more questions,

particularly those aligned with specific convergent NoS aspects, fostering a more engaging and reflective environment within NoS education (Kruse et al., 2020).

Furthermore, our exploration into the world of NoS conceptualizations revealed the dominance of closed NoS frameworks that align with teacher-centered ER definitions. In contrast, the less frequently used, but more open and mixed NoS frameworks harmonize with a student-centered approach to ER. In conclusion, our study underscores the need for ongoing research and discussion surrounding NoS education. Perhaps the era of traditional, closed approaches to NoS is coming to an end, paving the way for more open or mixed frameworks in the future. We can't help but wonder—if we were to conduct the same study in ten years, what results would we find?

This work was supported by the University of Antwerp grant 44616.

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<https://doi.org/10.1007/s11165-018-9732-9>

Prospective Mathematics Teachers' Perceptions of Infinity and Their Academic Knowledge About the Arithmetic of Infinity

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ABSTRACT

This study examines prospective mathematics teachers' perceptions of infinity and their academic knowledge of the arithmetic of infinity. A concurrent nested mixed-methods design was employed. The participants consisted of 100 volunteer third- and fourth-year prospective teachers enrolled in a mathematics teacher education program at a state university in the Aegean Region of Türkiye during the 2024–2025 academic year. Data were collected in a classroom setting via an online form comprising one open-ended question and 24 multiple-choice items. The open-ended question aimed to elicit participants' conceptual perceptions of infinity, while the multiple-choice items assessed their academic knowledge of arithmetic operations involving infinity. In particular, participants' understandings of operations involving ∞ with ∞ , 1, 0, and π were examined separately. Qualitative data were analyzed using descriptive analysis, whereas quantitative data were analyzed using descriptive statistics. The findings indicate that prospective teachers' perceptions of infinity are predominantly grounded in potential infinity rather than actual infinity. Although their overall performance on arithmetic operations involving infinity was above average, notable difficulties emerged, particularly in operations involving ∞ and 0. The results further reveal that intuition-based perceptions of infinity negatively reflect prospective teachers' procedural performance in operations involving infinity. When interpreted through the combined lenses of conceptual change theory and APOS theory, the findings suggest that prospective teachers have not successfully undergone a conceptual shift from potential to actual infinity and that their understanding of infinity has largely not been constructed at the object level.

Keywords: Infinity, actual infinity, potential infinity, arithmetic of infinity, prospective mathematics teacher

Introduction

Concepts play a central role in mathematics and mathematics education, shaping how mathematical ideas are constructed, understood, and communicated. Among these concepts, infinity is widely regarded as one of the most intriguing and cognitively demanding notions. Reasoning about infinity requires learners to move beyond finite experiences and intuitive forms of thinking, engaging instead with abstract entities that cannot be completed, measured, or directly perceived. Consequently, infinity poses substantial cognitive, epistemological, and pedagogical challenges (İşleyen, 2013; Yıldırım & Keşan, 2017).

At the outset, it is important to distinguish between two fundamental conceptions of infinity: potential infinity and actual infinity (Manfreda-Kolar & Hodnik-Čadež, 2012). Potential infinity refers to an endless, never-completed process, such as counting the natural numbers, whereas actual infinity denotes a completed infinite entity, such as the set of all natural numbers conceived as a whole (Manfreda-Kolar & Hodnik-Čadež, 2012; Sabery et al., 2024). Although this distinction is fundamental to modern mathematics, empirical research consistently shows that learners tend to rely

on process-based interpretations (potential infinity), which often leads to resistance toward accepting actual infinity as a legitimate mathematical object (Cihlár et al., 2015; Díaz-Espinoza et al., 2023; Krátká et al., 2021). The well-known question of whether $0.999\dots$ equals 1, frequently discussed in the literature, illustrates the tension between potential and actual infinity (Cihlár et al., 2015; Díaz-Espinoza et al., 2023; Díaz-Espinoza et al., 2024; Juter, 2019). From the perspective of potential infinity, $0.999\dots$ is viewed as an endlessly continuing process that never reaches completion and is therefore perceived as different from 1. From the perspective of actual infinity, however, $0.999\dots$ is interpreted as a completed infinite sum and thus considered equal to 1.

The distinction between potential and actual infinity has been elaborated in numerous studies (Dubinsky et al., 2005; Fischbein, 2001; Hannula et al., 2006; Manfreda-Kolar & Hodnik-Čadež, 2012; Moore, 1995; Tall, 2001). Historically, this distinction can be traced back to Aristotle and was later developed by Kant (Akbulut & Akgün, 2005). The potential character of infinity is rooted in the Aristotelian tradition (Luis et al., 1991) and dominated mathematical thought until the latter part of the 19th century (Linnebo & Shapiro, 2017). Two major turning points marked the historical development of actual infinity: the work of Bernard Bolzano (1851), who introduced actual infinity to resolve paradoxical situations, and the work of Georg Cantor (1883), who formalized infinity as a mathematical object (Luis et al., 1991). Although actual infinity has contributed profoundly to the foundations of modern mathematics, it has remained conceptually controversial despite the comprehensive framework provided by Cantor's theory (Tsamir & Dreyfus, 2002). Aristotle viewed infinity as comprehensible only through potential infinity, whereas Cantor argued that potential infinity lacks meaning unless grounded in actual infinity (Cantor, 1883). Aristotle characterized actual infinity as existing at a single moment and potential infinity as unfolding over time (Moore, 1995).

From a pedagogical perspective, the distinction between potential and actual infinity is particularly important for elementary teachers, as their underlying conceptions shape how mathematical ideas are explained, represented, and discussed in the classroom. Teachers who predominantly rely on potential infinity tend to emphasize endless processes, which may lead to ambiguous or incomplete explanations of concepts such as repeating decimals, number line density, and numerical magnitude. In contrast, an understanding of actual infinity allows teachers to conceptualize infinite entities as completed objects, supporting more coherent explanations and preventing the transmission of common misconceptions. Therefore, identifying which type of infinity understanding pre-service teachers rely on is critical for evaluating their readiness to support students' conceptual development.

Theoretical Framework: Conceptual Change Theory and APOS Theory

Research grounded in conceptual change theory indicates that difficulties related to infinity do not merely stem from procedural errors but rather from deeply rooted cognitive structures developed through individuals' finite experiences. Intuitive forms of reasoning that are productive in everyday contexts become insufficient when learners are required to reason about completed infinite entities. According to the conceptual change approach, students often make sense of scientific concepts through intuitive explanations based on their everyday experiences, and they tend to resist these concepts when such explanations conflict with scientific understanding (Vosniadou, 1994; Vosniadou et al., 2008). Consequently, learning about infinity requires not the simple addition of new information but a reorganization of existing conceptual frameworks (Vosniadou & Verschaffel, 2004). Fischbein (2001) emphasizes that actual infinity is particularly resistant to cognition because it fundamentally conflicts with intuitive modes of thinking. According to conceptual change theory, as proposed by Posner et al. (1982), individuals abandon their existing conceptions only when they experience dissatisfaction with them and perceive the new conception as intelligible, plausible, and

fruitful. In this respect, infinity, due to its highly abstract nature, represents one of the most prominent cases of conflict between intuitive reasoning and formal mathematical understanding (Fischbein, 2001).

This process of conceptual restructuring can be examined in greater detail through APOS (Action–Process–Object–Schema) theory (Dubinsky & McDonald, 2001; Dubinsky et al., 2005). According to APOS theory, mathematical understanding develops through a progression from action to process, from process to object, and ultimately to schema (Dubinsky et al., 2005). At the action stage, individuals perform operations mechanically, often in response to external instructions (Dubinsky & McDonald, 2001). At the process stage, these actions are internalized, enabling mental control over the operation. At the object stage, the process is encapsulated into a coherent whole that can itself be manipulated as a mathematical entity (Dubinsky & McDonald, 2001). Finally, a schema represents an integrated cognitive structure that connects this object with related mathematical concepts (Dubinsky & McDonald, 2001; Dubinsky et al., 2005). Studies conducted in the context of infinity indicate that prospective teachers often remain at the action or process level; while they may respond correctly to certain expressions involving infinity, understanding indeterminate forms such as $\infty - \infty$ or $\infty \div \infty$ requires object-level reasoning (Hannula et al., 2006). Difficulties in achieving this process–object transition constitute one of the fundamental conceptual obstacles in understanding infinity.

Perceptions of Infinity and Arithmetic Operations Involving Infinity

Previous research has demonstrated that perceptions of infinity across different educational levels are largely grounded in potential and process-oriented interpretations (Dev & Çetin, 2023; Durak et al., 2025). Many participants, including prospective teachers, tend to conceptualize infinity as an “ongoing” and “endless” process, while object-based interpretations remain limited (Manfreda-Kolar & Hodnik-Čadež, 2012; Oflaz & Polat, 2022). This predominance of process-based reasoning is closely associated with the conceptual and procedural difficulties observed in arithmetic operations involving infinity.

The literature indicates relatively high rates of correct responses for operations such as $\infty + \infty$, $1 \cdot \infty$, and ∞^n ($n \in \mathbb{Z}^+$). In contrast, participants frequently conflate the notions of infinity, undefined, and indeterminate when dealing with indeterminate forms such as $\infty - \infty$, ∞^0 , $0 \cdot \infty$, and $\infty \div 0$ (Çelik & Akşan, 2013; Oflaz & Polat, 2022; Sırmacı & Gökkurt-Özdemir, 2016). Some studies have also reported that both students and teachers tend to treat infinity as a numerical entity, rather than as a conceptual construct with context-dependent meaning (İşleyen, 2013; Yıldırım & Keşan, 2017). Collectively, these findings underscore the strong relationship between perceptions of infinity and arithmetic competence in operations involving infinite quantities.

Epistemological and Pedagogical Dimensions of Infinity

Beyond cognitive challenges, infinity also poses significant epistemological difficulties (İşleyen, 2013; Yıldırım & Keşan, 2017). Learners frequently conflate infinity with undefined or indeterminate expressions, particularly in arithmetic contexts (Çelik & Akşan, 2013; Oflaz & Polat, 2022; Sırmacı & Gökkurt-Özdemir, 2016). These confusions reflect not only conceptual gaps but also uncertainty about the nature of mathematical existence and validity. Researchers have found that mathematics teachers’ mathematical knowledge levels are related to their students’ mathematical achievement (Hill et al., 2005). Even for elementary teachers, who may not deal with infinity directly in their curricula, knowledge of infinity is important. Many researchers have found that effective teachers know not only the content they teach directly, but also how that content fits into the larger

subject (Ball et al., 2008; Ma, 2010; Shulman, 1986). Therefore, for mathematics teachers to engage in confident and meaningful mathematical discussions in their classrooms and to support students' mathematical learning, their mathematical knowledge should not be limited to the curriculum level they teach but should also include an understanding of the underlying foundations of mathematical concepts.

In prospective mathematics teacher education programs, the concept of infinity occupies a central place in many core mathematics courses, particularly in analysis, where it is fundamental to understanding limits, convergence, and continuity. Pre-service teachers are expected to develop a sound and coherent understanding of this concept in order to make sense of advanced mathematical ideas. Although the concept of infinity is not explicitly taught in elementary grades, it is implicitly embedded in many elementary mathematics topics such as number line representations, fractions, repeating decimals, patterns, and the idea of numerical density. Elementary teachers' conceptions of infinity influence how these topics are explained, represented, and discussed in the classroom, and limited or incorrect understandings of infinity may be unintentionally transferred to students and shape their early mathematical intuitions. Accordingly, this study investigates pre-service teachers' perceptions and academic knowledge regarding the concept of infinity, which is considered a foundational concept underlying many mathematical ideas.

Previous studies consistently report persistent misconceptions about infinity across different educational levels (Bozkuş et al., 2015; Hannula et al., 2006; Oflaz & Polat, 2022). More recent research indicates that prospective teachers continue to interpret infinity predominantly in terms of potential infinity (Dev & Çetin, 2023; Durak et al., 2025). This dominant process-based view is closely linked to difficulties in arithmetic operations involving infinity. Although success rates are relatively high for operations such as $\infty + \infty$, $1 \cdot \infty$, and ∞^n , indeterminate forms such as $\infty - \infty$, ∞^0 , $0 \cdot \infty$, and $\infty \div 0$ remain problematic (Çelik & Akşan, 2013; Oflaz & Polat, 2022; Sırmacı & Gökkurt-Özdemir, 2016). Moreover, some studies show that students and even teachers treat infinity as a number (İşleyen, 2013; Yıldırım & Keşan, 2017).

Overall, the literature highlights a strong relationship between infinity conceptions and performance in arithmetic operations involving infinity. Accordingly, the present study aims to examine prospective mathematics teachers' perceptions of infinity and their academic knowledge of arithmetic operations involving ∞ , 0, 1, and π . The study is guided by the following research questions:

- How do prospective mathematics teachers perceive infinity?
- How well do prospective mathematics teachers solve problems involving operations with ∞ , 0, 1, and π ?

Methods

In this study, a concurrent nested mixed-method design was used—quantitative and qualitative data were collected together, but emphasis was given to quantitative data (Baki & Gökçek, 2012; Creswell, 2014; Yıldırım & Şimşek, 2016).

Study Group of the Research

The study group of the research consisted of 100 volunteer prospective teachers studying in the third and fourth grades of the Department of Mathematics Education at a state university in the Aegean Region of Türkiye in the spring semester of the 2024-2025 academic year. These prospective teachers are enrolled in a four-year undergraduate teacher education program in Türkiye. At the time

of the study, 54 of the participants were in their third year, and 46 were in their fourth year of this university program. Upon graduation, these prospective teachers are qualified to teach mathematics at the lower secondary level (middle school), specifically to students in Grades 5 through 8 (approximately ages 10–14) in Türkiye. The study group of the research was determined by a criterion sampling technique, one of the purposeful sampling methods (Patton, 2001). The criterion used was that participants successfully completed the courses Analysis I, Analysis II, and Analysis III, which are the courses dealing with infinity and different variations of limit. In addition, since these prospective teachers were in the final years of their programs, they had completed most of the mathematics and mathematics education courses required by the curriculum. Therefore, it can be argued that these preservice teachers had many opportunities to learn about infinity.

In the curriculum of the mathematics teacher education program in Türkiye, prospective teachers are required to take a series of Analysis courses beginning in their first semester, in accordance with the course content prescribed by the Council of Higher Education (Council of Higher Education [CoHE], 2018). These courses, titled Analysis I, Analysis II, and Analysis III, are sequentially offered across consecutive semesters. In Türkiye, prospective teachers are first introduced to the concept of limits—particularly those involving multivariable functions—within these Analysis courses. Alongside fundamental concepts, the curriculum includes topics such as the limits of single-variable functions at a point and the limits of two-variable functions, which are treated as a continuation of the previous topics in successive courses. In the Analysis courses, prospective teachers study topics that address the concept of infinity and related arithmetic operations within various limit contexts. Table 1 presents detailed information regarding the content of the Analysis courses.

Table 1

Contents of Analysis I, Analysis II, and Analysis III courses (CoHE, 2018)

Analysis I	Analysis II	Analysis III
Sets and number systems; relations, types of functions, exponential functions, and logarithmic functions; limits, continuity concepts, and their applications; derivatives, applications of derivatives, and graphing (p. 4).	Trigonometric functions, trigonometric relations, solutions of trigonometric equations; complex numbers and their properties; Riemann sum, definite integral, indefinite integral, methods of integration, applications of integration, improper integrals, series and convergence tests (p. 6).	Multivariable functions; topology of $\mathbb{R}^n$, limit, continuity, function sequences and series; derivative, directional derivative, partial derivative, geometric interpretation of partial derivative, higher-order derivatives and chain rule (p. 7).

Data Collection Tool and Data Collection Process of the Research

The data of the study were collected using an online form consisting of 25 questions in total, one open-ended and 24 multiple-choice problems with basic arithmetic operations related to infinity, compiled and expanded from mathematics and mathematics education literature (Aşık, 2010; Çelik & Akşan, 2013; Oflaz & Polat, 2022; Sergeyev, 2003; Sırmacı & Gökkurt-Özdemir, 2016). The open-ended question aims to determine the perceptions of infinity of prospective mathematics teachers. This question is “*What comes to your mind when you hear the word infinity? Explain*” question. Multiple-choice questions are aimed at determining the academic knowledge of prospective teachers regarding the arithmetic of infinity. Multiple-choice questions consist of four parts. The first part consists of the operations involving ∞ and ∞ , the second part consists of the operations involving ∞ and 1, the third part consists of the operations involving ∞ and 0, and the fourth part consists of

the operations involving ∞ and π . Each part consists of six questions. Of the 24 multiple-choice questions, 10 have the correct answer ∞ , seven have the correct answer indeterminate, five have the correct answer 0, and two have the correct answer $-\infty$. Participants were given 25 minutes to complete the form. The form is presented in Appendix-1.

Participants accessed and answered the questions in class during the spring semester of the 2024-2025 academic year. Prospective teachers accessed the form via the link sent and submitted their answers individually within the set 25-minute period.

Data Analysis

The responses to the open-ended question in the online form were analyzed using qualitative descriptive analysis. For this purpose, four codes were used: *actual infinity*, *potential infinity*, *both actual and potential infinity*, and *meaningless*. The responses of prospective teachers who perceived infinity as an object or a completed entity were coded as *actual infinity*, the responses of prospective teachers who perceived it as an ever-continuing process were coded as *potential infinity*, and the responses referring to both the process and the object were coded as *both actual and potential infinity*. Answers other than these, which have nothing to do with infinity, were coded as *meaningless*. The frequencies and percentages of the codes obtained are reflected in Table 1.

Each correct answer to multiple-choice questions was scored as one point, and each wrong or blank answer was scored as zero points. These data were analyzed with quantitative descriptive statistics through the aforementioned spreadsheet and statistics program. The arithmetic mean scores obtained from the answers given to 24 multiple-choice questions are presented and interpreted in Table 2. In addition, the arithmetic mean scores of the responses to the operations ∞ and ∞ , ∞ and 1, ∞ and 0, and ∞ and π are also reflected and interpreted in this table according to separate class levels. In addition, minimum and maximum scores are given and interpreted as additional information. The frequency and percentage values of correct answers given to each multiple-choice question are presented and interpreted in Table 3 according to class levels in four parts.

Validity and Reliability Studies

The researchers tried to ensure and increase the internal and external validity and reliability (Büyükoztürk et al., 2016; Creswell, 2014; Karasar, 2014; Yıldırım & Şimşek, 2016) of the study. For the content validity of the form, expert opinions (Büyükoztürk et al., 2016; Creswell, 2014; Hair et al., 2014) were taken from a professor from the departments of mathematics and mathematics education. In this context, opinions were received from experts on whether the form was intended to determine prospective mathematics teachers' perceptions of infinity and their academic knowledge about the arithmetic of infinity.

In line with these views, the number of multiple-choice questions was reduced from 30 to 24. Questions $-\infty - \infty$, $(+\infty) - (-\infty)$, $(-\infty) \cdot (-\infty)$, $\pi - (-\infty)$, $(-1)^\infty$, and $n \in \mathbb{Z}^+$ while ∞^n were removed from the form in order to both reduce the number of questions and eliminate similar questions. Thus, the total number of questions in the form became 25, including the open-ended question. In addition, the time to answer the form has been reduced from 30 minutes to 25 minutes. Data were collected in the participants' natural environment, preventing them from being exposed to any factors.

Qualitative descriptive analysis of the responses to the open-ended question was conducted separately by both authors. For this purpose, two codes determined within the theoretical framework of the research were used. These codes are the codes of *actual infinity* and *potential infinity*.

Thus, out of 100 codes, 90 were found to be compatible and 10 were found to be incompatible. The agreement percentage between the coders was calculated as $\frac{90}{90+10} = 90\%$ using the “*reliability = $\frac{\text{number of agreements}}{\text{total number of agreements+disagreements}}$* ” formula of Miles and Huberman (1994, p. 64). It was determined that eight of the incompatible responses contained expressions regarding perceptions of both actual and potential infinity. The answers of the two prospective teachers did not fall into any of these categories. In order to resolve the incompatibilities, *both the actual and potential infinity* code and the *meaningless* code were included in the coding, and the frequency and percentage values of these four codes are reflected in Table 1. For example, below is a sample statement from a prospective teacher that evokes both potential and actual infinity.

When I think of infinity, a concept that has no end or ending comes to mind. In mathematics, numbers continue forever; in the universe, time and space can be thought of as infinite. It expresses a magnitude or continuity that has no end.

Although authors initially disagreed by attempting to determine the dominant side in this statement, they resolved their disagreements by including such statements in both the actual and potential infinity categories. In addition, participant responses to these four different codes are presented to the reader with verbatim quotes (Guba & Lincoln, 1981).

Quantitative descriptive statistics of the responses to multiple-choice questions were made by one of the authors using a spreadsheet program and by the other author using a statistics program, and the results were compared. No disagreements were found in these results.

Finally, the open-ended and multiple-choice questions in the data collection tool are given in the appendix, and the online and classroom data collection process is presented to the reader in detail. The four codes and examples in the qualitative data analysis and the process of reaching the scores and values in the quantitative data analysis are also described in the same way.

Findings

In this section, the findings of the research questions “*How do prospective mathematics teachers perceive infinity?*” and “*How well do prospective mathematics teachers solve problems involving operations with ∞ , 0, 1, and π ?*” are presented, respectively.

Perceptions of Infinity of Prospective Mathematics Teachers

In the first stage of the study, the aim was to reveal prospective teachers’ perceptions of infinity. For this purpose, prospective teachers were asked the question, “*What comes to your mind when you hear the word infinity? Explain.*” All prospective teachers have a perception about infinity; there is no prospective teacher who left this open-ended question unanswered.

An analysis of their responses indicated that the answers could be grouped into four main categories. Table 2 presents detailed information regarding prospective teachers’ perceptions of the concept of infinity.

Table 2*Perceptions of Infinity by Prospective Teachers*

Perception of Infinity	Grade 3		Grade 4		Grade 3 and 4	
	f	%	f	%	f	%
Actual infinity	23	42.59	14	30.44	37	37.0
Potential infinity	26	48.15	27	58.70	53	53.0
Both actual and potential infinity	3	5.56	5	10.87	8	8.0
Meaningless	2	3.70	0	0	2	2.0
Total	54	100	46	100	100	100

Note. Percentage values have been rounded to the hundredths.

As seen in Table 2, prospective mathematics teachers' perceptions of infinity are more frequently associated with potential infinity (53%). However, perceptions related to actual infinity (37%) also have a considerable percentage and ratio. The percentage of prospective teachers who use expressions related to both actual and potential infinity is 8%. Only two prospective teachers (2%) gave meaningless answers. No prospective teachers were encountered who left the question blank. The order of frequencies and percentages of these codes (potential, actual, both actual and potential, meaningless) does not change in the perceptions of both third and fourth-grade prospective teachers. However, in the perceptions of third-grade prospective teachers, the percentages of actual infinity and potential infinity are closer to each other. Accordingly, these findings indicate that the majority of prospective teachers perceive infinity intuitively as an unending process. It can be stated that a substantial proportion of the prospective teachers are able to construct the concept of infinity as a mathematical object. This suggests that, at least partially, a conceptual change has occurred. Moreover, the small number of prospective teachers who adopted both types of infinity demonstrates their ability to transform intuition-based views of infinite processes into mathematically structured objects, indicating a more advanced level of conceptual change.

Prospective teachers with perceptions related to potential infinity mostly wrote answers that infinity is a never-ending, beginningless, and endless, ever-continuing, increasing, or multiplying process. Verbatim quotes from the answers of seven prospective teachers with perceptions related to potential infinity are given below.

- “A situation that has no end, never ends, is continuous and ongoing.”
- “It means that it has no end, never ends, and is constantly continuing.”
- “Unending, continuing, constantly increasing.”
- “A situation that has no beginning or end, that is constantly advancing or regressing.”
- “Having no end, always continuing.”
- “The absence of any end means that it is constantly continuing.”
- “A concept that is unending, with no beginning or end.”

Prospective teachers who have perceptions related to actual infinity often expressed infinity as an infinite set or object. In addition, some of these prospective teachers wrote statements about the infinity of the world, space, or the universe. Verbatim quotes from the responses of six prospective teachers who have perceptions related to actual infinity are given below.

- “An infinite set, a set of solutions that can take any value.”
- “Infinity reminds me of the universe.”
- “Outer space.”

“A collection of objects that has no end comes to mind. In other words, a set that contains every number I can think of.”

“A collection of objects that has no end.”

“An endless collection of objects.”

Expressions related to both actual and potential infinity were encountered in the answers of eight prospective teachers. These prospective teachers have included both process- and object-oriented expressions separately. Verbatim quotes from the answers of four prospective teachers who wrote answers related to both actual and potential infinity are given below.

“When I think of infinity, a concept that has no end or ending comes to mind. In mathematics, numbers continue forever; in the universe, time and space can be thought of as infinite. It expresses a magnitude or continuity that has no end.”

“When I think of infinity, what comes to my mind is limitless, endless, the infinity of the universe, something that has no beginning or end.”

“Endless, space, right.”

“Endless, limitless, the universe that has no beginning or end.”

Both prospective teachers coded as “meaningless” wrote the answer “indeterminate”. These prospective teachers think that the concepts of infinity and indeterminate express the same thing.

Academic Knowledge of Prospective Mathematics Teachers Regarding the Arithmetic of Infinity

Following the examination of prospective teachers’ perceptions of the concept of infinity, their responses to the 24 multiple-choice questions were analyzed. The results are presented in Table 3.

Table 3

Descriptive Statistics Values for the Arithmetic of Infinity

	Part	Number of Questions	N_3	N_4	$N_{3 \text{ and } 4}$	$\overline{X_3}$	$\overline{X_4}$	$\overline{X_{3 \text{ and } 4}}$
Part 1	∞ and ∞	6	54	46	100	3.32	4.87	4.03
Part 2	∞ and 1	6	54	46	100	4.33	5.61	4.92
Part 3	∞ and 0	6	54	46	100	1.85	3.17	2.46
Part 4	∞ and π	6	54	46	100	4.41	5.24	4.79
Total		24	54	46	100	13.91	18.89	16.20

Note. Arithmetic mean values have been rounded to the hundredths.

As seen in Table 3, prospective mathematics teachers answered, on average, 16.20 out of 24 items correctly, corresponding to a success rate of approximately 67.5%. Considering that 12 correct responses (50%) represent the midpoint of the test, this result indicates that the prospective teachers’ academic knowledge of the arithmetic of infinity is above the midpoint level. Fourth-grade prospective teachers are more successful than third-grade prospective teachers in the arithmetic of infinity ($\overline{X_4}=18.89>\overline{X_3}=13.91$). Prospective mathematics teachers were least in the operations of

∞ and 0. This was especially true for third-grade prospective teachers, but also held true for fourth-grade prospective teachers. The operations that prospective mathematics teachers are most successful at are ∞ and 1. According to the grade levels, fourth-grade prospective teachers were most successful in operations with ∞ and 1, while third-grade prospective teachers were most successful in operations with ∞ and π . As additional information, the minimum score for third-grade prospective teachers is six, and the maximum score is 21, while the minimum score for fourth-grade prospective teachers is eight, and the maximum score is 22. In other words, the prospective mathematics teacher with the lowest number of correct answers was able to answer six questions out of 24 multiple-choice questions correctly, while the prospective teacher with the highest number of correct answers was able to answer 22 questions correctly.

The frequency and percentage values of the correct answers given by the prospective mathematics teachers to each multiple-choice question are presented in Table 4 in parts according to their grade levels.

Table 4

Frequency and Percentage Values for the Arithmetic of Infinity

Part	Question No	Question	Correct Answer					
			Grade 3 ($N_3 = 54$)		Grade 4 ($N_4 = 46$)		Grade 3 and 4 ($N_{3 \text{ and } 4} = 100$)	
			f	%	f	%	f	%
Part 1 ∞ and ∞	Question 1	$\infty + \infty$	45	83.33	45	97.83	90	90.0
	Question 2	$\infty - \infty$	23	42.59	38	82.61	61	61.0
	Question 3	$\infty \cdot \infty$	27	50.00	42	91.30	69	69.0
	Question 4	$\infty \div \infty$	34	62.96	38	82.61	72	72.0
	Question 5	$(-\infty) \div (-\infty)$	33	61.11	39	84.78	72	72.0
	Question 6	∞^∞	17	31.48	22	47.83	39	39.0
Part 2 ∞ and 1	Question 7	$\infty \div 1$	51	94.44	46	100.0	97	97.0
	Question 8	$1 \div \infty$	37	68.52	44	95.65	81	81.0
	Question 9	∞^1	48	88.89	44	95.65	92	92.0
	Question 10	1^∞	11	20.37	35	76.09	46	46.0
	Question 11	∞^{-1}	34	62.96	43	93.48	77	77.0
	Question 12	$1 \cdot \infty$	53	98.15	46	100.0	99	99.0
Part 3 ∞ and 0	Question 13	∞^0	14	25.93	35	76.09	49	49.0
	Question 14	$0 \cdot \infty$	9	16.67	33	71.74	42	42.0
	Question 15	0^∞	30	55.56	14	30.43	44	44.0
	Question 16	$0 \cdot (-\infty)$	12	22.22	31	67.39	43	43.0
	Question 17	$0 \div \infty$	31	57.41	30	65.22	61	61.0
	Question 18	$\infty \div 0$	4	7.41	3	6.52	7	7.0
Part 4 ∞ and π	Question 19	$\infty + \pi$	47	87.04	46	100.0	93	93.0
	Question 20	$\infty \div \pi$	38	70.37	38	82.61	76	76.0
	Question 21	$\pi - \infty$	35	64.81	36	78.26	71	71.0
	Question 22	$\pi \cdot (-\infty)$	45	83.33	43	93.48	88	88.0
	Question 23	π^∞	35	64.81	36	78.26	71	71.0
	Question 24	$\pi^{-\infty}$	38	70.37	42	91.30	80	80.0
Total			751	57.95	869	78.71	1620	67.5

Note. Percentage values have been rounded to the hundredths.

When considered on a question-by-question basis, the question that prospective mathematics teachers are least successful at (7%) is the $\infty \div 0$ question. In this question, the majority of the prospective teachers (80%) chose option undefined, 12% of the remaining ones chose option indeterminate, 7% options ∞ , and 1% option 0. The question that prospective mathematics teachers are most successful at (99%) is question $1 \cdot \infty$. All fourth-grade prospective teachers (100%) and almost all third-grade prospective teachers (98.15%) gave the correct answer to this question.

When considered on the part basis, the question that prospective mathematics teachers are least successful in regarding ∞ and ∞ operations is ∞^∞ . Only 39% of the prospective mathematics teachers chose the correct answer option ∞ , 48% chose option indeterminate, 11% chose option undefined, and the remaining 2% chose option 0. In this question, undefined and indeterminate were the distractors for the prospective teachers. The question that prospective mathematics teachers are most successful at (90%) in ∞ and ∞ operations is $\infty + \infty$. More than half of the fourth-grade prospective teachers were able to choose the correct answer for all other ∞ and ∞ operations. The majority of third-grade prospective teachers could not mark the correct answer in the $\infty - \infty$ question in addition to the ∞^∞ question. The percentage of correct answers is 42.59. The distractor options for this question were 0 and ∞ . 13 third-grade prospective teachers (24.07%) chose the answer 0, and again 13 third-grade prospective teachers (24.07%) chose the answer ∞ . Half of the third-grade prospective teachers were able to answer the question $\infty \cdot \infty$ correctly. $\infty \div \infty$ and $(-\infty) \div (-\infty)$ indeterminates are the indeterminates in which pre-service elementary mathematics teachers have the highest percentage (72%) among 1^∞ , ∞^0 , $0 \cdot \infty$, $0 \cdot (-\infty)$, $\infty - \infty$, $\infty \div \infty$, $(-\infty) \div (-\infty)$ indeterminates, that is, they are the most successful.

The highest percentage of correct answers for ∞ and 1 operations is the $1 \cdot \infty$ question mentioned above, which has the highest percentage (99%) among all questions. The question with the lowest correct percentage (46%) in the operations ∞ and 1 is the only question in this section with an indeterminate answer, namely 1^∞ . There is no question that more than half of the fourth-grade prospective teachers answered incorrectly. However, the correct percentage of third-grade prospective teachers for question 1^∞ was 20.37%, while the incorrect percentage was 79.63%. 38 third-grade prospective teachers (70.37%) marked the answer 1 in this indeterminate question. The majority of third-grade prospective teachers were able to mark the correct options in other ∞ and 1 operations except for this question.

In the operations of ∞ and 0, the majority of the prospective mathematics teachers could not mark the correct answer in the questions of ∞^0 , $0 \cdot \infty$, 0^∞ , $0 \cdot (-\infty)$, and $\infty \div 0$, except for the question of $0 \div \infty$. The lowest percentage of correct answers for ∞ and 0 operations is the $\infty \div 0$ question mentioned above, which has the lowest percentage (7%) among all questions. The majority of fourth-grade prospective teachers could not mark the correct answer in the 0^∞ and $\infty \div 0$ questions, and the majority of third-grade prospective teachers could not mark the correct answer in the ∞^0 , $0 \cdot \infty$, $0 \cdot (-\infty)$, and $0 \div \infty$ questions. In question ∞^0 , 1, in the question $0 \cdot \infty$, 0, in the question 0^∞ , indeterminate, in the question $0 \cdot (-\infty)$, 0, and in the question $\infty \div 0$, undefined and indeterminate were the distractor options.

In the operations of ∞ and π , the majority of prospective mathematics teachers were able to mark the correct answer in all questions. The majority of both third-grade and fourth-grade prospective teachers were able to mark the correct options in all questions. The highest correct percentage (93%) belongs to the question $\infty + \pi$ (93%), while the lowest correct percentage (71%) belongs to the questions $\pi - \infty$ and π^∞ .

Considering the grade level, fourth-grade prospective teachers were more successful than third-grade prospective teachers in all questions related to the operations ∞ and ∞ , ∞ and 1, and ∞ and π . In the questions about the operations ∞ and 0, the correct percentage of third-grade prospective teachers is higher than the fourth-grade prospective teachers only in the questions 0^∞ and $\infty \div 0$. In the other four questions, it is seen that the correct percentage of fourth-grade prospective teachers is higher than the third-grade prospective teachers.

Discussion

The first results of the study are related to the perceptions of infinity of prospective mathematics teachers. It was determined that the perceptions of infinity of prospective mathematics teachers were more frequently related to potential infinity (Cihlár et al., 2015; Díaz-Espinoza et al., 2023; Díaz-Espinoza et al., 2024; Krátká et al., 2021). In their study aimed at improving high school mathematics teachers' conceptions of infinity, Díaz-Espinoza et al. (2023) reported that the teachers predominantly held a potential conception of infinity prior to the intervention, and that they showed resistance to changing this conception even after the instructional activities. This finding revealed that the potential conception of infinity represents a robust and persistent cognitive image. Similarly, İşleyen (2013) found in his study that the understanding of potential infinity was dominant among high school students. Dev and Çetin (2023) determined in their study that all of the metaphors produced by high school students about infinity were related to potential infinity.

Although the perceptions related to potential infinity were more intense in our study, the perceptions related to actual infinity were also considerable. Especially in the perceptions of third-grade prospective teachers, the percentages of actual infinity and potential infinity are closer to each other. In their study examining prospective teachers' understanding of the concept of infinity and the factors affecting these understandings, Manfreda-Kolar and Hodnik-Čadež (2012) revealed that prospective teachers' justifications for solving tasks related to infinity were based on both actual and potential infinity. Oflaz and Polat (2022) revealed that students of the mathematics department and mathematics teaching department evaluate infinity as operational, intuitive, potential, and actual infinity, and that they have such understandings about infinity. In order to conceptualize infinity and internalize the arithmetic of infinity, both the concepts of actual and potential infinity are needed. Therefore, it can be suggested that this distinction should be conveyed to prospective teachers along with its historical processes in teacher preparation programs.

Prospective mathematics teachers who have perceptions related to potential infinity mostly (53%) described infinity as a process that has no beginning or end, never ends, continues continuously, and increases or decreases continuously. Prospective teachers (37%) who have perceptions related to actual infinity also mostly described infinity as an infinite set or object. Some have also written statements about the infinity of the world, space, or the universe. In a similar study, Maria et al. (2010), who investigated whether teachers' perceptions of infinity were a process or an object, found that approximately two-thirds of the teachers (72.1%) defined infinity as a process, and the rest (27.9%) defined it as an object. Teachers who defined infinity as a process used expressions such as "it goes on forever," "it's a process that never ends," "it has no beginning and no end...always follows another number," "keeps going and increasing," while teachers who defined infinity as an object used expressions such as "it is an infinite whole," "it is something countless," "it is a set with unlimited elements," and "it is an undefined set" (Maria et al., 2010, p. 1775). In these respects, the parallel aspects of the two studies are striking. In the studies of Oflaz and Polat (2022), while some of the mathematics and mathematics teaching students emphasize the ever-increasing aspect of infinity, some of them have an understanding of infinity as discussed by Cantor in the context of countable and uncountable infinite sets. Unlike the results of these studies, only one of

the 13 mathematics teachers in the study by Sırmacı and Gökkurt-Özdemir (2016) expressed infinity as a process.

In the answers of eight prospective teachers, expressions related to both actual and potential infinity were encountered. These prospective teachers used expressions in which they described infinity as both a process and an object. It is also interesting that only two prospective teachers' perceptions of infinity were evaluated in the meaningless category. 98 prospective teachers were able to give meaningful answers, while two prospective teachers gave a meaningless answer by writing "indeterminate." Çelik and Akşan (2013) also asked prospective mathematics teachers the question "*Explain the concept of infinity in your own words*" and the answers of 16 out of 83 participants were evaluated in the category of incorrect explanation because they generally referred to undefined and indeterminate (pp. 173-174). Although there is a difference in the frequencies of the prospective teachers who gave meaningless and incorrect answers in the two studies, their references to indeterminate may be an example of their misperceptions about infinity. These misconceptions may affect the learning of infinity-related topics (e.g. limit and series) and even courses (e.g., Analysis) in teacher education. It may be beneficial for instructors of courses involving infinity in teacher education to be aware of these misconceptions for their teaching.

From the perspective of conceptual change theory, findings indicate that more than half of the prospective teachers (53%) perceived infinity in terms of potential infinity, describing it as an "endless, continuously ongoing process." This result is consistent with a substantial body of literature suggesting that human cognition exhibits a natural tendency toward potential infinity (Dubinsky et al., 2005; Fischbein, 2001; Hannula et al., 2006). This tendency implies that prospective teachers have not yet experienced dissatisfaction with their existing intuitive conceptions and, therefore, have not reconstructed infinity as a completed mathematical object. The fact that 37% of the prospective teachers expressed infinity in terms of actual infinity suggests that conceptual change has partially occurred for some individuals. However, the finding that only 8% simultaneously considered both potential and actual infinity reveals that relatively few prospective teachers have developed a coherent and integrated cognitive structure linking these two conceptions. According to conceptual change theory, this indicates that most prospective teachers remain unable to abandon intuition-based reasoning grounded in potential infinity and continue to interpret actual infinity within this intuitive framework (Posner et al., 1982; Vosniadou, 1994; Vosniadou et al., 2008).

As shown in Table 3, the prospective mathematics teachers answered an average of 16.20 items correctly on the 24-item arithmetic of infinity test. This score exceeds the midpoint of the test, which corresponds to 12 correct responses (50%), and represents an overall success rate of approximately 67.5%. Accordingly, this finding indicates that the prospective teachers' academic knowledge of the arithmetic of infinity is above the midpoint level of the assessment. When examined by grade level, fourth-year prospective teachers demonstrated higher performance than third-year prospective teachers. This difference may be attributed to the fourth-year students' greater exposure to advanced mathematical content, theoretical coursework, and pedagogical training throughout the teacher education program. In a similar vein, Hannula et al. (2006) reported that, in parallel with age-related cognitive development, learners tend to develop more appropriate and structured conceptions of infinity. Beyond overall performance and grade-level differences, distinct patterns were also observed across different types of infinity operations. Specifically, prospective teachers showed lower performance on operations involving ∞ and 0 compared to their performance on other infinity-related operations. In contrast, operations involving ∞ and 1 were those in which prospective teachers were most successful. This pattern suggests that prospective teachers may tend to perceive infinity as an invariant quantity, which leads to conceptual difficulties particularly in operations involving 0, whereas operations involving 1 may be approached using more intuitive and rule-based reasoning. These findings highlight the need to address conceptual

limitations related to the arithmetic of infinity more explicitly within mathematics teacher education programs.

A detailed examination of the responses to the questions revealed that prospective mathematics teachers were most successful in operations involving $\infty + \infty$ and $\infty \div \infty$. In particular, the majority of both third- and fourth-year prospective teachers correctly identified $\infty + \infty$ as ∞ , with higher success rates observed among fourth-year students. Similarly, $\infty \div \infty$ and $(-\infty) \div (-\infty)$ were the indeterminate forms with the highest rates of correct responses. In contrast, operations such as $\infty - \infty$, ∞^0 , 1^∞ , $0 \cdot \infty$, and $0 \cdot (-\infty)$ were found to be the most challenging. In these cases, many prospective teachers selected distractor options such as 0, 1, ∞ , or “undefined,” indicating persistent conceptual confusion. Third-year prospective teachers were generally less successful than fourth-year students, particularly in recognizing indeterminate forms. For operations involving ∞ and 1, almost all prospective teachers correctly answered $1 \cdot \infty$, whereas 1^∞ was among the least correctly answered questions, often being interpreted as 1. In operations involving ∞ and 0, only $0 \div \infty$ yielded relatively high correct response rates, while $\infty \div 0$ was frequently misinterpreted as undefined. These results suggest that 0 and 1 function as strong distractors alongside ∞ , indeterminate, and undefined in the arithmetic of infinity. As a contribution beyond the existing literature, this study also examined operations involving π and infinity. The results showed that prospective teachers generally did not experience difficulty with these operations. Overall, the findings reveal that prospective teachers frequently confuse the concepts of infinity, indeterminate, undefined, 0, and 1, particularly in operations requiring object-level reasoning about infinity. Taken together, these results are consistent with previous studies reporting similar misconceptions and difficulties related to the arithmetic of infinity and indeterminate forms (Çelik & Akşan, 2013; İşleyen, 2013; Oflaz & Polat, 2022; Sırmacı & Gökkurt-Özdemir, 2016; Yıldırım & Keşan, 2017).

When prospective teachers’ achievement in arithmetic operations involving infinity is examined within the framework of APOS theory, a clear pattern emerges. The high success rates observed in operations such as $\infty + \infty$, $\infty \cdot 1$, and $\infty + \pi$ suggest that prospective teachers tend to approach these operations primarily at the action or process level. Because such operations can be intuitively generalized as “infinity is already very large,” they can often be answered correctly without requiring a deep level of objectification. In contrast, the substantial decline in success rates for operations such as $\infty - \infty$, $0 \cdot \infty$, $\infty \div \infty$, $\infty \div 0$, and ∞^∞ indicates that prospective teachers experience considerable difficulty in conceptualizing infinity at the object level. In particular, the fact that the correct response rate for the $\infty \div 0$ item was only 7% reveals that the distinctions among infinity, indeterminacy, and undefinedness have not been adequately constructed at the object stage of APOS theory. According to APOS theory, the transformation of a process into an object requires individuals to conceive the process as a coherent whole and to perform mental operations on it (Dubinsky & McDonald, 2001). The findings suggest that most prospective teachers continue to interpret infinity as an “ongoing process,” which leads to cognitive conflict when confronting indeterminate forms such as $\infty - \infty$ or $0 \cdot \infty$. This helps explain why the options “indeterminate” and “undefined” function as strong distractors, particularly in items such as ∞^∞ and 1^∞ .

Finally, the findings revealed that prospective teachers’ conceptions of infinity are directly reflected in their performance in the arithmetic of infinity. The results indicate that most prospective teachers predominantly hold a potential infinity perspective, conceptualizing infinity intuitively as an endless, continuously increasing process. Within this framework, they were relatively successful in operations whose results are infinite, whereas they experienced considerable difficulty in situations involving indeterminate forms. In other words, prospective teachers tended to perform well in contexts that can be addressed through potential infinity reasoning but struggled in cases that require an object-level understanding of actual infinity. This finding demonstrates that prospective teachers’ perceptions of infinity are closely associated with their arithmetic reasoning involving

infinity. This central result is in direct alignment with the theoretical framework of the study. When conceptual change theory and APOS theory are considered together, the findings suggest that prospective teachers' learning process regarding the concept of infinity remains largely incomplete. Intuitive understandings grounded in potential infinity continue to dominate among a substantial proportion of prospective teachers. Unless such intuitive structures give rise to sufficient cognitive conflict, as proposed by conceptual change theory, the construction of actual infinity as a mathematical object becomes difficult. In particular, the observed performance gap between operations yielding infinite results (e.g., $\infty + 1$, $\infty \cdot \pi$) and operations yielding indeterminate results (e.g., $\infty - \infty$, $0 \cdot \infty$, $\infty \div \infty$) clearly indicates that prospective teachers succeed when intuitive generalizations are sufficient but encounter difficulties in situations that require objectification. From the perspective of APOS theory, this pattern points to an incomplete transition from process to object, while from a conceptual change perspective, it suggests that prospective teachers have not yet experienced an adequate level of dissatisfaction with their existing conceptions.

Conclusion and Recommendations

This study examined prospective mathematics teachers' perceptions of infinity and how these perceptions are reflected in their understanding of the arithmetic of infinity. The findings indicate that the majority of prospective teachers predominantly conceptualize infinity in terms of potential infinity, while fewer demonstrate an understanding of actual infinity, and only a small number are able to coordinate both perspectives. Given that intuitive, process-based views of infinity may lead to systematic errors in abstract mathematical contexts, these results highlight the need for instructional practices that support prospective teachers' conceptual transition toward actual infinity. In particular, teacher education programs should incorporate learning experiences that explicitly promote the objectification of infinity and support its construction at the object level.

Another important finding of the study is that prospective teachers' success in operations involving infinity varies considerably depending on the type of operation. While participants generally performed well on operations whose outcomes are infinite, they experienced substantial difficulty with operations that result in indeterminate forms (e.g., $\infty - \infty$, $0 \cdot \infty$, $\infty \div \infty$). This pattern suggests that prospective teachers' understanding of infinity often remains at the process level, which is sufficient for handling intuitive generalizations but inadequate for situations requiring object-level reasoning. Given that limit situations and indeterminate forms play a central role across many areas of mathematics, instructional efforts should aim to ensure that these concepts are understood not merely procedurally but as coherent mathematical objects. In this respect, the adoption of APOS-based instructional approaches is strongly recommended for teaching the arithmetic of infinity. Instruction should be designed to support prospective teachers' progression from action and process levels to object-level reasoning, particularly in contexts involving indeterminate forms. Emphasizing infinity as a completed mathematical entity and engaging learners in reasoning about its properties may help reduce persistent misconceptions and foster deeper conceptual understanding.

Finally, the findings demonstrate a clear relationship between prospective teachers' conceptions of infinity and their performance in arithmetic operations involving infinity. The dominance of potential infinity appears to be a key factor underlying many of the observed difficulties. This central result is consistent with the theoretical framework of the study. When considered together, conceptual change theory and APOS theory suggest that prospective teachers' learning of the concept of infinity remains largely incomplete, as the intuitive, process-based understanding has not yet been sufficiently challenged to trigger the cognitive conflict necessary for restructuring. Future research may further investigate this relationship using alternative theoretical perspectives and research designs. In particular, experimental and longitudinal studies focusing on

instructional interventions aimed at fostering an understanding of actual infinity could provide valuable insights for improving teacher education practices.

Limitations

Despite its contributions, this study has several limitations that should be considered when interpreting the findings. First, the study focused on prospective mathematics teachers in their third and fourth years of study at a single state university. Therefore, the findings may not be directly generalizable to other contexts, institutions, or educational levels.

Second, the qualitative component of the study was limited to responses obtained from a single open-ended question, while the quantitative findings were based on a structured multiple-choice instrument developed for this research. Although this design allowed participants to express their reasoning with minimal constraints, it may not have fully captured the depth and complexity of their conceptual understandings. Future research could replicate the study using different research designs, such as in-depth interviews, think-aloud protocols, or classroom-based interventions, to gain richer insights into prospective teachers' reasoning about infinity.

The authors received no financial support for the research, authorship, and/or publication of this manuscript

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Appendix-1: Form

Informed Consent and Assent Guide: Dear prospective mathematics teachers, this form has been prepared to examine your perceptions of infinity and your academic knowledge about the arithmetic of infinity. The data obtained from this form will be used in the scientific study titled “<i>Prospective mathematics teachers’ perceptions of infinity and their academic knowledge about the arithmetic of infinity</i>”, with the right to change the name, and your identity will remain confidential. This form consists of one open-ended and 24 multiple-choice questions. This form will be applied to you online in a classroom environment and you will be given 25 minutes for this. Your participation in this research is voluntary. You can participate in the research, refuse to participate, or withdraw from the research at any time after participation. When you participate in the research, you will not face any risks during the research. You will never face any negative consequences if you do not participate in the research or withdraw from the research. In addition, if you withdraw from the research, your data will be removed from the scope of the research. Before the research, you need to have detailed information about the purpose, scope, duration of the research, and your participation rights. You can ask the researcher any unclear issues and questions you want before or during the research. If you decide to participate, do not be under anyone's influence or pressure while answering the form. “I have read and understood the Informed Consent and Assent Guide.” ☐ I want to participate in the research of my own free will. ☐ I do not want to participate in the research. 1. What comes to your mind when you hear the word infinity? Explain.		
Questions	Correct Answer	Brief Explanation
$\infty + \infty$	∞	Adding two unbounded quantities results in an unbounded (infinite) quantity. Example: $\lim_{x \rightarrow \infty} (x + x) = \infty$.
$\infty - \infty$	Indeterminate	The difference between two unbounded quantities can take any value depending on their growth rates. Example: $\lim_{x \rightarrow \infty} (x - x) = 0$ and $\lim_{x \rightarrow \infty} (2x - x) = \infty$.
$\infty \cdot \infty$	∞	The product of two unbounded positive quantities diverges to infinity. Example: $\lim_{x \rightarrow \infty} (x \cdot x) = \infty$.
$\infty \div \infty$	Indeterminate	The ratio of two unbounded quantities depends on their rates of growth. Example: $\lim_{x \rightarrow \infty} \left(\frac{x}{x}\right) = 1$, $\lim_{x \rightarrow \infty} \left(\frac{x^2}{x}\right) = \infty$, $\lim_{x \rightarrow \infty} \left(\frac{x}{x^2}\right) = 0$.
$(-\infty) \div (-\infty)$	Indeterminate	Although signs cancel, both numerator and denominator are unbounded; thus, the limit form remains indeterminate.
∞^∞	∞	An unbounded base raised to an unbounded positive exponent diverges to infinity. Example: $\lim_{x \rightarrow \infty} (x^x) = \infty$.
$\infty \div 1$	∞	Dividing an unbounded quantity by a finite nonzero constant remains unbounded. Example: $\lim_{x \rightarrow \infty} \left(\frac{x}{1}\right) = \infty$.
$1 \div \infty$	0	As the denominator grows without bound, the fraction approaches zero. Example: $\lim_{x \rightarrow \infty} \left(\frac{1}{x}\right) = 0$.
∞^1	∞	Any unbounded quantity raised to the power of 1 remains unbounded. Example: $\lim_{x \rightarrow \infty} (x^1) = \infty$.
1^∞	Indeterminate	Although the base is 1, limits of the form (1^∞) can approach values other than 1 depending on the rate of approach.

		Example: $\lim_{x \rightarrow \infty} \left(1 + \frac{1}{x}\right)^x = e$, $\lim_{x \rightarrow \infty} \left(1 + \frac{1}{x}\right)^{x^2} = \infty$.
∞^{-1}	0	The reciprocal of an unbounded quantity approaches zero. Example: $\lim_{x \rightarrow \infty} x^{-1} = 0$.
$1 \cdot \infty$	∞	Multiplying a finite nonzero constant by an unbounded value remains unbounded. $\lim_{x \rightarrow \infty} 1 \cdot x = \infty$.
∞^0	Indeterminate	The limit form (∞^0) can produce different results depending on how base and exponent vary. Example: $\lim_{x \rightarrow \infty} (x)^{\frac{1}{x}} = 1$, $\lim_{x \rightarrow 0^+} \left(\frac{1}{x}\right)^{\sqrt{x}} = \infty$.
$0 \cdot \infty$	Indeterminate	The product of a vanishing term and an unbounded term depends on their rates of change. Example: $\lim_{x \rightarrow \infty} \left(\frac{x}{x}\right) = 1$, $\lim_{x \rightarrow \infty} \left(\frac{x}{x^2}\right) = 0$.
0^∞	0	Any positive number less than 1 raised to an unbounded power approaches zero. Example: $\lim_{x \rightarrow \infty} \left(\frac{1}{x}\right)^x = 0$.
$0 \cdot (-\infty)$	Indeterminate	The same reasoning as $0 \cdot \infty$; the sign depends on context, and the limit is indeterminate.
$0 \div \infty$	0	A vanishing quantity divided by an unbounded one approaches zero. Example: $\lim_{x \rightarrow \infty} \frac{\left(\frac{1}{x}\right)}{x} = 0$.
$\infty \div 0$	∞	In the limit form, Dividing infinity by zero approaches infinity. Example: $\lim_{x \rightarrow \infty} \frac{x}{\left(\frac{1}{x}\right)} = \infty$.
$\infty + \pi$	∞	Adding a finite constant to an unbounded value leaves it unbounded. Example: $\lim_{x \rightarrow \infty} (x + \pi) = \infty$.
$\infty \div \pi$	∞	Dividing an unbounded value by a finite positive constant remains unbounded. Example: $\lim_{x \rightarrow \infty} \left(\frac{x}{\pi}\right) = \infty$.
$\pi - \infty$	$-\infty$	Subtracting an unbounded positive value from a finite constant yields an unbounded negative result. Example: $\lim_{x \rightarrow \infty} (\pi - x) = -\infty$.
$\pi \cdot (-\infty)$	$-\infty$	Multiplying a finite positive constant by an unbounded negative quantity gives negative infinity. Example: $\lim_{x \rightarrow \infty} \pi \cdot (-x) = -\infty$.
π^∞	∞	Any constant greater than 1 raised to an unbounded power diverges to infinity. Example: $\lim_{x \rightarrow \infty} (\pi)^x = \infty$.
$\pi^{-\infty}$	0	A finite constant greater than 1 raised to a negative unbounded power approaches zero. Example: $\lim_{x \rightarrow \infty} (\pi)^{-x} = 0$.

What Do We Know About Teaching Statistics for Social Justice? A Scoping Review

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ABSTRACT

Teaching statistics for social justice (TS4SJ) empowers students to use statistical data analysis skills to make positive changes in their communities. The aim of this study is to describe the volume, characteristics, and nature of the current research regarding teaching statistics for social justice. This scoping review provides an examination of the literature from multiple database searches. Inclusion criteria consist of literature published between 2007 and 2023, an explicit connection to statistics education in Pre-K-12 or post-secondary settings, and an explicit or implicit mention of TS4SJ elements. The systematic search of the literature yielded 16 relevant results toward our goal of providing a description of the characteristics and range of literature regarding TS4SJ. Our scoping review results provide evidence of a dearth of empirical studies, as well as a description of explicit and implicit TS4SJ elements aligned with the Guidelines for Assessment and Instruction in Statistics Education (GAISE). Thus, the scoping review results have implications for future research and practice in statistics education.

Keywords: pre-service teacher; in-service teacher; statistics education; social justice

Introduction

Statistics has become an essential subject in schools because it serves as a bridge between mathematics and everyday life. While often grouped under the umbrella of mathematics in the school curriculum, statistics is distinct in several important ways. Unlike mathematics, which emphasizes deterministic reasoning and exact solutions, statistics relies on inductive reasoning, contextual understanding, and managing variability and uncertainty (Tran & Lee, 2015). Statistical questions emerge from real-world contexts, requiring decisions about data collection, measurement, and appropriate analysis methods. This emphasis on context—such as understanding why outliers exist or determining appropriate models for data interpretation—distinguishes statistical reasoning from purely mathematical reasoning, which tends to prioritize generalizable proofs and exact answers. Ben-Zvi and Garfield (2008) suggest that statistics education provides students with the necessary tools to analyze quantitative information in the world around them. Similarly, Ramirez et al. (2012) recognize that one of the main learning outcomes of statistics is to produce statistically literate individuals who can apply statistical thinking to their surroundings. Thus, providing students and teachers alike with opportunities to connect real-world phenomena to statistical concepts (e.g., indicators of central tendency) is particularly salient for statistical education.

As such, the PreK-12 Guidelines in Assessment and Instruction in Statistics Education II (GAISE II) respond to the pressing needs of the public for data and statistical literacy (GAISE College Report ASA Revision Committee, 2016). The GAISE II further reinforces the role of statistics in connecting mathematics to the world outside of school by outlining the utility of students evaluating statistical conclusions and legitimacy, as well as formulating analyses to navigate a data-driven world (Bargagliotti et al., 2020). The GAISE II provides a framework for teachers to situate statistics lessons in the context of events such as global pandemics, climate change, volatile economic shifts, and important social issues such as Black Lives Matter, so that students may apply their learning to authentic, meaningful prompts. Moreover, the National Council of Teachers of Mathematics (NCTM; 2024) *High School Mathematics Reimagined, Revitalized, and Relevant* identifies the importance of engaging students in statistical modeling so that they may develop, test, and refine models to solve contextually rich, complex problems. Therefore, the call for a statistics-specific education curriculum that is responsive to real-world problems has increased over the last two decades.

Recent research suggests that students need the opportunity to experience the influence mathematics has on the social world (Weiland, 2019). This is indicative of the sociopolitical shift occurring in mathematics education (Gutiérrez, 2013; Lerman, 2000) that centers on the salient questions of identity, knowledge, and power in the mathematics classroom (Harper, 2019). Thus, the increased demand for statistics education has encouraged collaboration among mathematicians and statisticians. The connection to the real world has increased the importance of statistics education and called for the development of these skills for students and citizens (Gal, 2000). In turn, there has been an increase in accessible resources for teachers (Ben-Zvi & Garfield, 2008). For instance, Moore (1997) suggests that students are more likely to develop a desire to learn statistics if they are provided with hands-on and relevant opportunities to do so. In an effort to advance statistics education in the classroom, teachers have incorporated authentic games and technology into their lessons (Ben-Zvi & Garfield, 2008). Despite these efforts, motivating teachers and students to engage with statistics remains a challenge.

To effectively foster a passion for statistical thinking in students, teachers require the appropriate tools and education. Teachers should have a strong understanding of statistical reasoning and context, as they play a vital role in K-12 statistics education (Oliveira & Henriques, 2019). In a study on teacher perspectives about statistical reasoning, Oliveira and Henriques (2019) found that teachers understood the importance of developing students' statistical reasoning skills. Teachers described challenges faced, such as a lack of statistical language among students and students not being acquainted with this type of learning (Oliveira & Henriques, 2019). Despite these notable challenges, students also lack the proper critical thinking skills necessary to be “literate” consumers of data. A lack of statistical literacy can increase the prevalence of negative stereotypes and misinformation, which often fuels racism, sexism, homophobia, and other forms of oppression. Thus, it is critical for mathematics teachers to possess not only a strong understanding of mathematical (i.e., statistical) and pedagogical content knowledge (PCK) but also a strong foundation in culturally relevant pedagogy (CRP) (NCTM, 2021). To accomplish this goal, some mathematics teacher educators advocate for extending teachers' foundations in CRP to provide culturally relevant lessons and experiences, teaching mathematics through a lens of social justice to promote students' civic engagement (Bartell, 2013; Gist et al., 2019). Consequently, some argue that improving mathematics education requires culturally relevant instruction. Here, we argue that the statistical analysis and interpretation of “real” data pertinent to the cultural, social, and emotional experiences of students is one means to enact culturally relevant instruction.

Therefore, increasing social justice teaching efforts in teacher preparation programs and teacher training is critical to provide teachers with another “tool for their toolkit” as well as to support students' development of statistical literacy. Teaching for social justice entails both the recognition of

the existence of class, gender, sexuality, economic, and racial disparities and the commitment to take action to challenge such injustices (Cochran-Smith et al., 2016). Teaching mathematics for social justice includes analyzing or reading the world (i.e., existing inequities) through mathematics, which informs taking action or rewriting the world (Gutstein, 2003, 2006). Within the discipline of mathematics, teaching for social justice includes empowering students to leverage their mathematical skills to analyze critical issues and take action (Abdulrahim & Orosco, 2020; Larnell et al., 2016). Due to the operationalization of statistics, which connects areas of mathematics and bridges mathematics and the real world (Kader & Jacobbe, 2013), a specific branch of teaching mathematics for social justice has developed—teaching statistics for social justice. To this end, we argue that statistics is uniquely positioned to serve as a medium for teaching for social justice, precisely because so many social, political, and economic issues are best understood—and misunderstood—through statistical claims. Yet, despite the growing emphasis on critical mathematics education, the specific field of teaching statistics for social justice remains underexamined. There is little systematic understanding of how this approach is being conceptualized or implemented in curriculum and instruction. This leads us to investigate the scope of the literature regarding teaching statistics for social justice.

Problem Statement

While a sociopolitical shift in education has created opportunities for some teachers and students to engage with social issues through mathematics and statistics, this shift has not been uniformly adopted across educational settings. In contexts where it is embraced, teachers and students can focus on social issues that allow them to belong, be informed, and work toward change in the classroom (Gutiérrez, 2013). Still, ongoing political and institutional challenges continue to limit such opportunities in many classrooms. As a whole, mathematics curriculum writers have struggled to achieve equity (Allestaht-Snyder & Hart, 2001). As early as the 1970s, scholars have argued that mathematics education and pedagogy are rooted in Eurocentric precepts and exclude the experiences of African Americans and minorities in America (Tate, 1994). Allestaht-Snyder & Hart (2001) noted that the achievement gap between white students and African Americans, Latinos, Native Americans, and poor students remains a concern for educators despite previous research stating that the gap had grown smaller. Now more than ever, a diverse mathematics curriculum is urgently needed to help close the gap for underrepresented populations in mathematics classrooms.

As the nation becomes more diverse, teaching and learning mathematics for social justice (TLMSJ) has become imperative to ensure all students are represented and develop social, political, and critical knowledge to advocate for underserved populations (Gutiérrez, 2013). Abdulrahim and Orosco (2020) argue that meeting the needs of diverse learners is one of the biggest challenges educators continue to face today. As mathematics curriculum and pedagogy continue to evolve, it is important that educators find ways to incorporate multicultural perspectives and sociopolitical views in the classroom. As the language of social justice, statistics is one instructional medium to help fill this void. Yet, what remains underexamined are current conceptualizations and actualizations of teaching and learning statistics for social justice in the extant statistics education literature. To address this gap in the literature, this paper presents a scoping review of existing research on the conceptualizations and actualizations of teaching and learning statistics for social justice.

In the following sections, we first present a review of the literature to explore the purposes and challenges presented in extant literature related to teaching for social justice in mathematics education and statistics education, as well as prior systematic reviews in social justice education. After the literature review, we discuss our theoretical grounding (teaching statistics with social justice) as the overarching lens used to examine the characteristics of the observed studies in the present scoping review. We then present the scoping review methods used to collect and analyze our data, as well as the measures taken to maximize the reliability and validity of the results. We conclude with a review

of our findings and a discussion of the relevant research considerations and implications for teaching and learning statistics.

Prior Systematic Reviews of Social Justice in Education

The section below is designed to bridge gaps in the literature between the broader field of education and statistics education as it relates to teaching for social justice. Prior systematic reviews of social justice research in education have examined the following themes: definitions and conceptualizations of social justice, teacher education and preparation for social justice, and intersectionality and the role of identity in social justice education. As noted earlier, to our knowledge, a systematic review of the use of social justice within statistics education does not exist. However, a number of previous systematic reviews highlight the complexity of defining and conceptualizing social justice in the broader field of educational research (e.g., Dover, 2009; North, 2008; Xenofontos et al., 2021). In the section below, we address the need for a more precise definition and application of social justice in statistics education, based on the aforementioned body of literature. Secondly, in the sections below, we explore the importance of teacher education in preparing educators to teach statistics through a social justice lens. This is accomplished by reviewing prior research within teacher education that sought to foster critical thinking and awareness of inequalities. Lastly, this section exposes a critical gap in the literature by exploring how social justice education has been integrated into different subject areas and grade levels, with a limited focus on mathematics education and statistics education specifically.

A more precise and operational definition of social justice is essential for advancing scholarship and practice in statistics education. Without clear definitions, educators and researchers may struggle to design curricula, assess impact, or evaluate pedagogical interventions grounded in social justice. Hytten and Bettez (2011) emphasize that social justice in education requires both the recognition of systemic inequities and a commitment to disrupting them—yet what that disruption looks like in practice, particularly within statistics instruction, is often underspecified. North (2008) adds that social justice also involves examining how power and privilege are embedded in educational systems, which raises critical questions about whose knowledge is centered in data selection, analysis, and interpretation. Thrupp and Lupton (2006) further argue that the broader social and economic conditions surrounding schools fundamentally shape what kinds of justice-oriented teaching are possible. Taken together, these syntheses reveal a conceptual gap: while the field acknowledges the importance of social justice, it lacks a shared framework for enacting it in discipline-specific ways. For statistics education in particular, this ambiguity makes it difficult to distinguish between surface-level applications of social justice themes and more transformative pedagogical approaches.

A second central theme explored in prior syntheses is the role of teacher education and preparation in cultivating a social justice orientation. Several scholars (Kaur, 2012; Mills & Ballantyne, 2016; Reagan & Hambacher, 2021; Wiedeman, 2002) emphasize that preservice and in-service teachers must be explicitly supported in critically examining their assumptions, identities, and positionalities to effectively enact social justice in their future classrooms. Kaur (2012) calls for teacher education programs to move beyond surface-level inclusion of equity topics and instead prioritize reflective practices that allow educators to interrogate their own biases and develop actionable commitments. Similarly, Mills and Ballantyne (2016) argue that preservice teachers benefit from immersive, experience-based learning opportunities that build lasting dispositions toward equity-focused teaching. Reagan and Hambacher (2021) add historical depth to the conversation, noting that social justice education must be situated within broader institutional narratives and power structures. Collectively, these reviews point to the importance of intentional, well-structured learning experiences in shaping educators who are prepared to integrate social justice meaningfully into their instruction. However, few studies specify how this preparation translates to subject-specific practices, including in statistics

education, which highlights a persistent disconnect between broad ideals and practical classroom enactment.

The third theme across prior syntheses concerns intersectionality and the central role of identity in shaping how social justice is conceptualized and enacted in education. Pugach et al. (2019) advocate for an intersectional approach that accounts for how individuals' multiple and overlapping identities, such as race, gender, class, and language, interact to influence experiences of privilege and marginalization. This lens challenges one-size-fits-all approaches to social justice pedagogy and highlights the need for nuanced, responsive teaching practices. Xenofontos et al. (2021) extend this idea into mathematics education, arguing that educators' own identities, shaped by their lived experiences, cultural backgrounds, and prior schooling, profoundly affect how they understand and promote social justice in their instruction. Building on this, Dover (2009) contends that teacher education must create space for educators to interrogate how their identities influence their beliefs, decisions, and pedagogical choices. In the context of statistics education, these findings suggest that educators' positionalities may shape which data are centered, which questions are asked, and how statistical claims are interpreted. Although identity development is a growing focus in mathematics and statistics education research, its connection to social justice remains underexamined (Pugach et al., 2019; Xenofontos et al., 2021). Prior syntheses affirm that identity is not just a background factor but a fundamental component in how social justice teaching takes shape, further underscoring the need for frameworks that explicitly link identity, power, and disciplinary practices in statistics education (Dover, 2009; North, 2008).

Aside from a limited number of prior systematic reviews on social justice in mathematics education, other gaps in the literature abound. Researchers observed that limited attention is given to the experiences and perspectives of students from marginalized backgrounds in social justice education research (Meister et al., 2017). The experiences of marginalized populations are an important consideration for statistics education as we, scholars and teacher educators, continue striving toward equitable learning outcomes for all students. Others identified a lack of research exploring the impact of social justice education on student outcomes (Dover, 2009). As we continue to develop processes, procedures, and policies to support student achievement in statistics, it is essential to consider the impact, or lack thereof, related to social justice education. Additionally, researchers suggest that the prior literature does not fully explore how social justice education can be integrated into different subject areas and grade levels (Capper et al., 2006). Given that there was only one systematic review on social justice in mathematics education, this gap in the literature is especially pertinent. Here we seek to help fill this gap by conducting the first systematic review, to our knowledge, that examines social justice within the context of statistics education.

Theoretical Underpinnings

Our scoping review utilizes Lesser's (2007) conceptualization of teaching statistics with social justice (TSSJ) to analyze the extant literature. Lesser (2007) expands Gutstein's (2003) Freirean description of using the critical lens of mathematics to statistics as a:

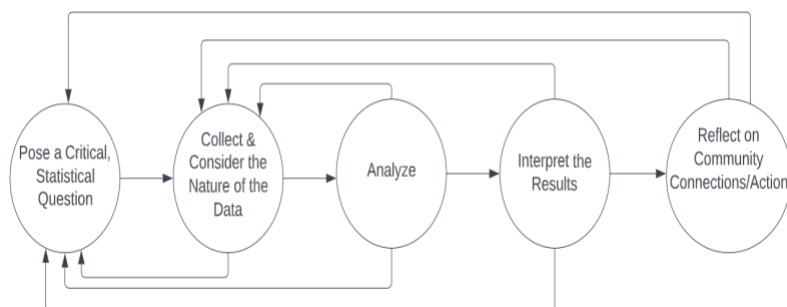
"Means to use mathematics to understand the relations of power, resources, inequities, and disparate opportunities between different social groups, and to understand explicit discrimination based on race, class, gender, language, and other differences. Further, it means to dissect and deconstruct media and other forms of representation and to use mathematics to examine these various phenomena both in one's immediate life and in the broader social world and to identify relationships and make connections between them" (p. 45).

This quote highlights Gutstein's (2003) argument that mathematics can be a tool for understanding and challenging social injustices. Gutstein (2003) posits that by critically examining data and representations, students can gain insights into power structures and inequalities that might otherwise remain hidden. Gutstein's (2003) examples of providing opportunities for students to analyze and question data and data representations lays the groundwork for understanding how a critical perspective can be brought into statistics education. To this end, Lesser (2007) defines TSSJ, more commonly known as teaching statistics for social justice (TS4SJ), as a method of statistical instruction that provides nontrivial contextualization, reflection, and application of social justice examples and statistics for students. TS4SJ represents the nexus of statistics *conceptual* and *computational proficiency* and *critical perspective*. The goals of TS4SJ are twofold: 1) students' data/statistical literacy and 2) students' application of statistical analyses to social justice issues (Figure 1). Lesser (2007) posits that TS4SJ prepares students to become part of a competitive workforce and to become active participants in a democracy. Of note, TS4SJ differs from other traditions in critical mathematics education such as teaching mathematics for social justice (Gutstein, 2003) and critical statistical literacy (Weiland, 2017) by focusing specifically on statistics education as well as empowering students to reflect and take action based on their findings from their critical analysis.

The belief that learning statistics is a mechanism to not only navigate daily life but also to catalyze social change in the world is foundational to TS4SJ (Lesser, 2007). For instance, teachers may use TS4SJ lessons in the context of social justice issues such as representation, internet access, wages, pollution, or health to situate students' statistics learning in authentic, meaningful scenarios (Knurek, 2021; Pollack & Wunderlich, 2005; Wall, 2016). Applying a critical lens to the operational definitions of variables (e.g., race, gender, poverty line) involves examining how these definitions are constructed, whose interests they serve, and what assumptions they embody. This approach provides students with ways to respond to and pose critical questions regarding the collection and nature of the data, as well as the systems from which the data originates. Thus, TS4SJ allows for an opportunity for students to reflect upon the relationship of the data to socio-political, geographic, cultural, or economic influences. Students are afforded space to "talk back" or pose arguments based on their statistical analyses and analyses of critical events (i.e., affordable housing, response to Lahaina fires). This empowers students with statistical knowledge to use data judiciously (Bargagliotti et al., 2020) by identifying inequities in their communities (Enyedy et al., 2006) and becoming agents of change (Dacia et al., 2021). To this end, TS4SJ provides the opportunity to extend the GAISE II statistical problem-solving process (Bargagliotti et al., 2020) beyond interpreting the results to allow students to make connections with their communities and create plans for action (Figure 1).

Figure 1

Teaching Statistics for Social Justice (Lesser 2007) with the Statistical Problem-Solving Process (Bargagliotti et al., 2020)



When pre-service teachers (PSTs) participate in TS4SJ learning, they develop a better understanding of how social issues can help enhance and guide statistical learning in the classroom. For instance, Nguyen and Eisenreich (2018) found that K-8 PSTs gained awareness of social issues and content knowledge by participating in teaching statistics for social justice (TS4J) lessons that situate sampling issues and two-way frequency tables of school voucher programs. Furthermore, Register and colleagues (2022) support the need for PSTs to participate in social justice lessons as learners to obtain a more robust understanding of how to adopt the strategy. For social justice to become an attribute of educational practice, it is essential to provide mathematics teachers with appropriate pedagogical training to successfully interweave mathematics standards and social justice initiatives (Garii & Appova, 2013). PSTs and in-service teachers should continuously be provided with these opportunities to engage in TS4SJ as learners in order to prepare to incorporate this practice in the classroom.

Present Study

TS4SJ empowers students to use statistical data analysis skills to make positive change in their communities. Lesser (2007) concludes that statistics are numbers with context, and therefore TS4SJ equips students with the necessary skills to analyze and interpret the world. To this end, we seek to answer the following research questions:

1. What are the characteristics of works published on teaching statistics for social justice?
2. How has teaching statistics for social justice been described and implemented in the literature?

Method

Researchers are increasingly using scoping reviews to describe the volume, characteristics, and nature of the research they are conducting (Arksey & O'Malley, 2005; Cacchione, 2016; Daudt et al., 2013; Levac et al., 2010; Pham et al., 2014). When there is an absence of syntheses available (i.e., systematic reviews, meta-analyses), scoping reviews provide a precursor to describe the range of research. Researchers utilize the scoping review method to map disparate literature surrounding a specific policy or practice to inform next steps for research (Joanna Briggs Institute, JBI, 2015). Due to the widespread dispersal of research on TS4SJ across evidence and publication types, as well as an absence of synthesis of empirical evidence, we found it appropriate to conduct a scoping review of the existing literature (Barker et al., 2020; Mays et al., 2001). As such, we seek to inform future research and practice regarding TS4SJ by describing the volume, characteristics, and nature of the current research.

As scoping reviews have become more widely utilized, researchers have refined Arksey and O'Malley's (2005) original framework to provide improved rigor and consistency among scholars. Arksey and O'Malley (2005) originally outlined the following scoping review steps: 1) identify the research question; 2) identify relevant studies; 3) select studies; 4) chart the data; 5) collate/summarize/report results; and 6) optionally consult with consumers and stakeholders. Levac et al. (2010) expanded the original scoping review framework to include the adaptations: 1) clarify the purpose and connection to the research question(s); 2) balance feasibility with breadth/comprehensiveness; 3) utilize an iterative team approach to the search and extraction processes; 4) include a numeric summary of qualitative themes; 5) identify implications of the study findings; and 6) require consultation with consumers or stakeholders.

The Joanna Briggs Institute (JBI) (2015) protocol builds on the aforementioned scoping review frameworks. JBI (2015) set a minimum research team size of $n = 2$ to agree on the study design

(i.e., inclusion and exclusion criteria, extraction information). The scoping review protocol from JBI (2015) bolsters the first requirement from Arksey and O'Malley (2005) and Levac et al. (2010) to align the title of the scoping review study with its purpose and research questions. Further, the title of the scoping review must be in alignment with the inclusion/exclusion criteria identified for the study (e.g., population, context, practice). In addition, authors must provide a background of the scoping review topic to situate the study within the existing literature. Under the JBI (2015) scoping review, clear definitions of inclusion/exclusion criteria are required. This adds a level of transparency and rigor previously not required in the Arksey and O'Malley (2005) and Levac et al. (2010) scoping review frameworks. Furthermore, the JBI (2015) scoping review protocol requires authors to organize the included records from the search with information extraction to be presented in a table. JBI (2015) provides reporting recommendations such as authors, year of publication, purpose, participants, and methodology. To attend to rigor and fidelity as the scoping review method is advanced and refined, our scoping review follows the JBI (2015) protocol and reporting guidelines.

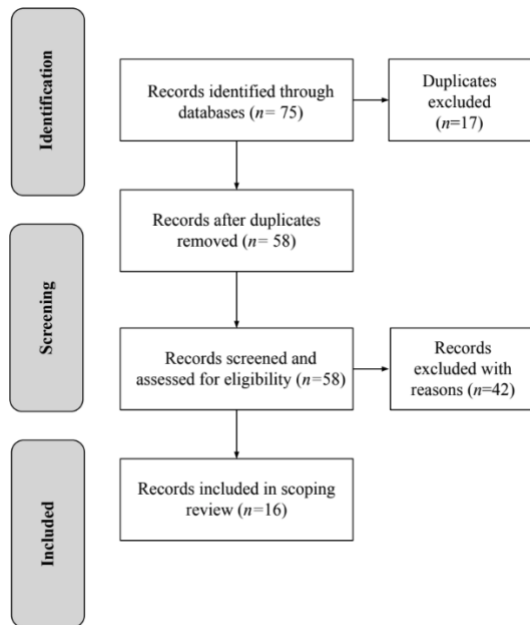
Data Collection

Inclusion criteria

Prior to carrying out database searches, the research team of two mathematics education researchers identified inclusion criteria (Figure 2) for screening articles. To determine the scope of the literature since the inception of TS4SJ from Lesser (2007), only works from 2007 to the present were included. To explore the range of the limited scholarship on TS4SJ, records were not limited to academic journal articles but included practitioner articles, dissertations, and book chapters as well. Only records published in English were included. Using the GAISE II and College GAISE frameworks, titles and abstracts were required to include a clear, explicit connection to statistics in K-12 or post-secondary education (Bargagliotti et al., 2020; GAISE College Report ASA Revision Committee, 2016). Further, the records had to include explicit or implicit mentions of TS4SJ elements in the title or abstract (Table 1).

Search strategy

To ensure consistent search results, we ran the database search procedure as a team. In alignment with our purpose of describing the characteristics and range of the existing literature on TS4SJ, we utilized the databases Academic Search Ultimate, ERIC, APA PsycInfo, and Education Full Text. The aforementioned databases offer broad access to texts from the humanities and social sciences, including texts such as journal articles and edited book chapters. Our search terms were “statistics education” OR “teaching statistics” AND “social justice,” with a separate search in each database for “critical statistical literacy.” This search approach yielded an initial pool of $n = 75$ records, including $n = 17$ duplicates (see Figure 2). The search terms were used in the aforementioned databases, which are also included in Figure 2. When conducting the searches in the databases, we did not limit the search terms to components of the literature (e.g., titles, abstracts, full text). Our rationale for conducting a scoping review is further strengthened by the relatively small pool of results.

Figure 2*Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flowchart of Study Selection***Screening**

Following the database search and removal of duplicates, the initial pool of records was reduced from 75 to 58 unique entries. To ensure alignment with the goals of our scoping review, we applied the inclusion criteria described earlier, which required records to (a) be published between 2007 and 2023, (b) include an explicit connection to statistics education in Pre-K-12 or post-secondary settings, and (c) contain either explicit or implicit mention of teaching statistics for social justice (TS4SJ) elements within the title or abstract. These criteria reflect our commitment to identifying literature that engages with the conceptual and instructional dimensions of TS4SJ as described by Lesser (2007). For inter-reviewer agreement, two reviewers screened an initial subset of three abstracts. We reached a 100% consensus threshold during this calibration phase by discussing the alignment of the abstracts with our inclusion criteria. Our conversations during calibration helped to ensure a shared and consistent understanding of the inclusion criteria prior to independent screening. This approach is recommended in scoping review methodology to increase rigor and mitigate subjective bias during study selection (Joanna Briggs Institute, 2015; Levac et al., 2010). Once consensus was established, the remaining abstracts were screened independently, with any disagreements discussed and resolved collaboratively. This iterative process ultimately yielded 16 records that met all inclusion criteria and were selected for full data extraction and analysis.

Extraction

Information from the included records was extracted using a Google Form (Table 1). To ensure reviewer consistency for extraction, we examined two articles together with the Google Form. We extracted information pertaining to the type of publication (i.e., empirical, non-empirical). The representation, characterization, and operationalization of TS4SJ were also coded dichotomously as either *explicit* or *implicit*. Records that utilized an *explicit* characterization identified the strategy as TS4SJ explicitly and provided examples to justify the designation, while studies that utilized an *implicit*

approach provided a description of the activities involved that alluded to or could be characterized as TS4SJ, but did not explicitly define the process as such. To examine the application of TS4SJ to statistics standards, we extracted information regarding the GAISE standards utilized in the records (Table 1).

Table 1

Record Coding Rubric

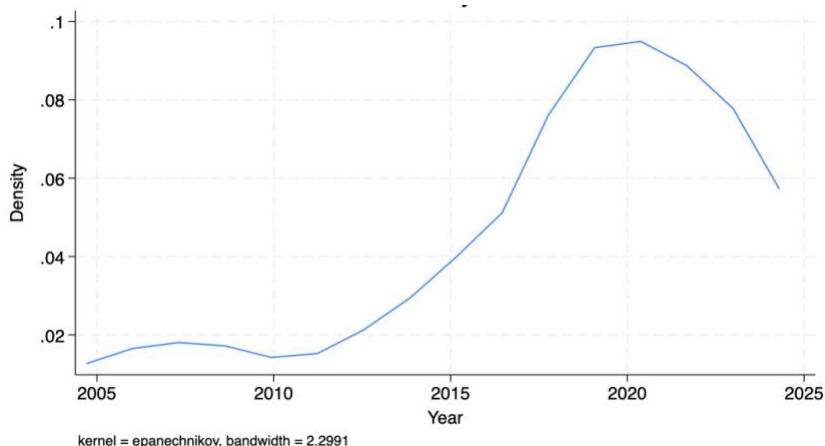
Topic	Item	Description
Record Information	Purpose	Aim of study
	Research questions/hypotheses	
	Publication	Empirical, non-empirical
	Publication Type	Academic Journal Article, Practitioner Article, Book Chapter, Dissertation, Other
	Participants	Pre- or in-service teacher, K-12 student, post-secondary student
	Grade Level	EC-6, 4-8, 9-12, post-secondary, NA
	Methodology	Qualitative, quantitative, mixed methods, other
	Data Sources	Instruments
	Analysis	Methods
	Findings	Results
Explicit/ Implicit Mention of TS4SJ	Implications	Significance for research and practice
	Teaching mathematics for social justice	Re-centering mathematics curriculum and instruction to build upon marginalized students' experiences and investigate critical issues (Gutstein, 2006)
	Teaching statistics for social justice	Use of statistics to identify inequities in students' communities and empower students to become agents of change (Lesser, 2007; Dacia et al., 2021)
	Critical questions	Ask about operational definitions of variables (e.g., poverty line, ethnicity) (Lesser, 2007)
	Student empowerment	Agency gained through statistical reasoning and connections
	Talk-back	Formation of arguments based on statistical analysis of critical events (e.g., Lahania fires)
	Community	Analyzing the conditions of the community
	Reflect upon context	Analyze the data in relation to socio-political, geographic, cultural, or economic influences

Topic	Item	Description
	Issue-driven	Statistics teaching and learning is problematized and contextualized
	Other	Free response for reviewers to add any other key words pertaining to TS4SJ (e.g., critical statistical literacy)
Pre-K-12 GAISE II (Bargagliotti et al., 2020)	Questioning in Statistics	Questioning throughout the statistical problem-solving process
	Different data and variable types	There is evidence of traditional data (quantitative) and/or non-traditional data types (pictures, sound, words)
	Multivariable thinking in statistics	Multivariable thinking throughout Levels A, B, & C. As students advance they will develop tools for comparisons and associations
	Probability in statistics	Probabilistic thinking throughout Levels A, B, & C. Students can make formal and informal predictions beyond the scope of the data
	The role of technology in statistics and how it develops through the levels	The role of technology in statistics depends on access. Teaching statistics with technology can enhance learning
	Assessment in statistics	Assessment items that measure statistical reasoning
GAISE College Student Goal Alignment (GAISE College Report ASA Revision Committee, 2016)	Critical consumers	Critical consumption of statistically-based results
	Investigative process	Recognize and answer questions for which the investigative process is in statistics
	Graphing	Produce and interpret graphical displays and numerical summaries
	Variability	Recognize and be able to explain the central role of variability
	Randomness	Recognize and be able to explain the central role of randomness
	Statistical model application	Gain experience with how statistical models are used
	Statistical inference	Understand and apply the basic ideas of statistical inference
	Statistical software packages	Interpret and draw conclusions from statistical software
	Ethical issues	Demonstrate an awareness of ethical issues associated with sound statistical practice

Results

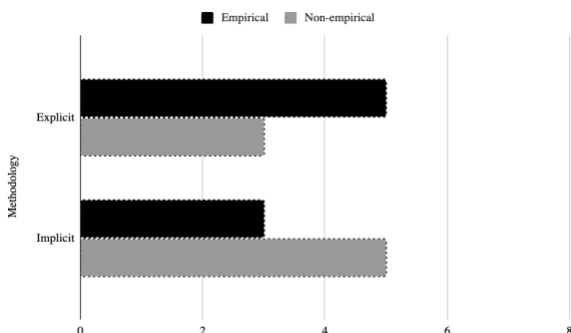
RQ1: Characteristics of works published on TS4SJ

The systematic search of the literature yielded 16 relevant results for our goal of providing a description of the characteristics and range of literature regarding TS4SJ. Following the JBI (2015) protocol recommendations for data reporting, Table 1 provides a complete list of the characteristics of the included records, including extracted data regarding the authors, year, purpose, study population, and methodology.

Figure 3*Kernel Density Plot of TS4SJ Publication Years*

The publication dates range from 2007 to 2023 (Table 1). As shown in Figure 3, the density of publications is greatest between the years 2019 and 2022, following the low density of publications after Lesser's (2007) inception of TS4SJ. The scoping review provides evidence of a dearth of empirical studies and methods (Tables 2 and 3). For instance, non-empirical records ($n = 10$) represent over half of the data set. Furthermore, there is a critical absence of traditional quantitative inquiry regarding TS4SJ, as the only sources of empirical evidence are qualitative ($n = 5$) and mixed methods ($n = 1$).

Furthermore, our results demonstrate that the majority of publications describe TS4SJ implicitly through the description of curriculum and instruction, including key attributes such as critical questions, student empowerment, talk back, community, reflection upon context, and issue-driven approaches (Lesser, 2007), as well as teaching mathematics and/or statistics through social justice (Figure 4, Table 3). Comparing explicit to implicit mentions of TS4SJ across methodologies, non-empirical publications explicitly use “teaching statistics for social justice” more frequently than empirical records that use qualitative and mixed methods combined (Figure 4, Table 3).

Figure 4*Frequency of Explicit and Implicit Mention of TS4SJ Across Methodologies*

Although the data reflect the limited quantity of existing literature, the range of participants, including in-service teachers, pre-service teachers, K-12 students, and post-secondary students, is fair (Table 3). In regard to K-12 grade level, the majority of TS4SJ tasks in the literature have a secondary

focus, with an emphasis on questioning through the statistical problem-solving process, data and variable types, and multivariable thinking (Table 3).

RQ2: Description and Implementation of TS4SJ

From this data, we identified four major themes across the records describing the implementation of TS4SJ: incorporating social justice in statistics education, using social justice data to teach statistics, teaching statistics for social justice in specific contexts, and developing critical statistical literacy for social justice.

The first theme, incorporating social justice in statistics education, refers to the trends of records seeking to add social justice-related content into the traditional statistics curriculum. Several records in the present scoping review discuss the importance of incorporating social justice into statistics education. This approach typically involves modifying course goals, instructional objectives, or lesson topics to include justice-oriented content, without necessarily altering the structure or format of traditional instruction. For instance, Conway and Nguyen (2020) used action research to explore the impact of incorporating social justice into pre-service teacher training, while Bergen (2016) suggested melding data with social justice in undergraduate statistics courses. Dacia et al. (2021), in an autoethnographic report, described how they incorporated social justice into their statistics instruction by rethinking data examples and instructional framing. These studies illustrate a shift toward recontextualizing statistics instruction to include critical social issues, even when those changes do not fundamentally alter the pedagogical format.

The second theme was using social justice data to teach statistics. Unlike the first theme, this theme seeks to use “real-world” data that concerns social justice issues as a means to apply traditional statistics knowledge. In this model, the structure of the statistics lesson may remain conventional, but the data sets themselves are deliberately chosen to center sociopolitical issues, thereby connecting students’ learning to real-world phenomena. Data from this scoping review indicates that several recent studies used social justice data to teach statistics. Louie et al. (2021) promoted interest in statistics by using social justice data investigations, while Wall (2016) used wealth data to teach statistics and its impact on quality of life. One specific example from the literature is Loux and Gibson (2019), who used water data from Flint, Michigan, in an introductory statistics course as a class assignment. Another key example is how Lasater et al. (2022) explored a complex gender wage gap dataset through data visualization. Together, these studies represent an important pedagogical tradition incorporating “real-world” data. While these studies may not foreground social justice as a curricular goal, they leverage the content of the data as a way to deepen student interest and awareness of injustice. The key distinction from the first theme is that social justice, in this case, is primarily a vehicle for statistical learning, rather than a goal of instruction in and of itself.

The third theme was teaching statistics for social justice in a specific context. In this category, instruction is designed around authentic, real-world problems that are central to students’ communities or to broader societal concerns. Studies exploring teaching statistics for social justice in specific contexts typically take place in a project-based, contextualized pedagogical environment. For instance, Maloney (2015) explored teaching introductory statistics using social justice contexts in community colleges through different projects related to societal issues. Others used more specific societal contexts or social issues, like poverty or female body image. McCoy (2008) explored teaching students about poverty through a statistics project, while Frydryk (2017) examined issues surrounding female body image and Barbie using a project-based learning example. These examples go beyond thematic or data-driven integration to involve students in the active exploration and construction of knowledge. Here, statistics becomes both a tool and a lens for examining social realities. Unlike the first two themes, where social justice is added to or illustrated through statistics instruction, these studies restructure the learning environment itself to center justice-oriented inquiry.

Lastly, the fourth theme, developing critical statistical literacy for social justice, focuses on cultivating students' abilities to question how data are constructed, represented, and interpreted, especially in relation to power and equity. This theme emphasizes skills such as evaluating variable definitions (e.g., race, poverty line), identifying bias in data collection, and understanding the implications of statistical claims. Studies in this category attend to the ways that statistics education can equip students to critically consume and challenge quantitative narratives. For example, Cannon (2022) described a course design that helped preservice teachers interrogate "messy" data and develop critical habits of mind. Krishnannair and Krishnannair (2022) made a theoretical case for critical statistical consciousness in higher education. In these cases, the goal is not just to use data about justice or embed justice themes, but to fundamentally reshape how students think about the nature and use of data itself. This theme is distinct in its emphasis on epistemology and critique, positioning students as informed skeptics and agents of accountability in a data-driven world.

Table 2

Evidence Chart of Characteristics of Included Literature

Record	Methodology	Publication Type	Participants	Grade Level	Purpose
Louie et al. (2022)	MM	AJA	IST, K-12 student	9-12	To promote diverse student populations' interests in working with data
Frydryk (2017)	NE	PA	K-12 student	EC-6	Discuss a lesson using TS4SJ where students form a question, collect data, analyze data, and interpret data using the Barbie body lesson from Mukhopadhyay (1998) for statistics
Amdat (2021)	NE	AJA	NA	Post-sec	Illustrates how the author used hardship index data in three different types of courses and includes additional ideas for classroom activities
Wall (2016)	NE	PA	NA	9-12	Communicate the value in teaching for social justice in a mathematics classroom by describing a lesson with the intent of empowering students to reach statistically sound conclusions that hold weight and change their perspectives through the vehicle of social justice
Knurek (2016)	NE	PA	NA	4-8, 9-12	Propose a lesson using the GAISE II framework that can be implemented into a statistics classroom. The lesson allows students to learn about the four components of the statistical problem-solving process as they interact with real-world data
Loux & Gibson (2019)	NE	AJA	Post-sec	Post-sec	Show Flint water crisis provided a starting point for discussions on sampling design, data collection, and ethical data practices
Lesser (2007)	NE	PA	K-12 student, Post-sec	9-12, Post-sec	Provides examples of TSSJ in different areas of statistics

Record	Methodology	Publication Type	Participants	Grade Level	Purpose
McCoy (2008)	NE	AJA	IST, K-12 student	9-12	Introduce what poverty is to students and give them an example of living in poverty
Cannon (2022)	NE	Book chapter	Pre-service teacher	NA	Report of a statistics course designed to build preservice teachers' pedagogical knowledge for statistics, comfort in working with messy data, and critical statistical literacy
Kahn et al. (2022)	NE	AJA	K-12 student	9-12	Introduce Notice, Wonder, Feel, Act, and Reimagine (NWFAR) to promote social justice in data science (DS) education
Krishnannair & Krishnannair (2022)	NE	AJA	NA	NA	Discuss theoretical underpinnings and applications of critical statistical literacy
Dacia et al. (2021)	Q	AJA	PST & Post-sec	Post-sec	Present a research base for teaching for social justice followed by a description of a lesson, observations during enactment, and reflection of change in beliefs about teaching for social justice afterward
Maloney (2015)	Q	Dissertation	Post-secondary	Post-sec	To investigate the way class activities designed around real-world social justice contexts help introductory statistics community college students develop an understanding of statistics concepts
Register et al. (2022)	Q	AJA	PST	4-8 & 9-12	To examine how PSTs use the CRMT tool to design social justice centered lessons
Conway & Nguyen (2020)	Q	AJA	PST, K-12 student	EC-6 & 4-8	To help future teachers, current teachers, and teacher educators begin to integrate TS4SJ.
Lasater et al. (2022)	Q	PA	K-12 student, Post-sec	Post-sec	Describe the distribution of a single variable and explore two-variable relationships within the gender wage gap

Note. MM = mixed methods; NE = non-empirical; Q = qualitative; AJA = academic journal article; PA = practitioner article; D = dissertation; NA = not applicable; Post-sec = post-secondary; PST = pre-service teachers; IST = in-service teachers

Table 3

Frequency trends across record characteristics

Category	Frequency
Method	
Mixed Methods	1
Qualitative	5
Quantitative	0
Non-empirical	10
Participants	
In-service Teachers	1
Pre-service Teachers	3
K-12 Students	4
Post-Secondary	3
Not applicable	5
Statistics Task Grade Level	
K-6	1
4-8	2
9-12	6
Post-secondary	7
Pre-K-12 GAISE II	
Questioning throughout the statistical problem-solving process	6
Different data and variable types	5
Multivariable thinking throughout Levels A, B, & C	3
Probabilistic thinking throughout Levels A, B, & C	0
The role of technology in statistics and how it develops through the levels	1
Assessment items that measure statistical reasoning	1
GAISE College Goal Alignment	
Students should become critical consumers of statistically-based results	2
Recognize and answer questions for which the investigative process in statistics	2
Produce and interpret graphical displays and numerical summaries	
Recognize and be able to explain the central role of variability	2
Recognize and be able to explain the central role of randomness in	1

Category	Frequency
Experience with how statistical models are used	2
Demonstrate an understanding of and ability to use basic ideas of statistical inference	2
Interpret and draw conclusions from standard output from statistical software	1
Demonstrate an awareness of ethical issues associated with sound statistical practice	2
Explicit Mention	
Teaching mathematics for social justice	8
Teaching statistics for social justice	8
Critical questions	3
Student empowerment	5
Talk back	1
Community	6
Reflect upon context	5
Issue-driven	7
Implicit Mention	
Teaching mathematics for social justice	8
Teaching statistics for social justice	8
Critical questions	10
Student empowerment	3
Talk back	3
Community	3
Reflect upon context	6
Issue-driven	5

Discussion

Teaching for social justice across all disciplines includes exploring diverse literature that has multicultural perspectives, considering the different impacts of political and economic decisions, and recognizing oppression caused by differences (Garii & Appova, 2013). However, in the present study, we argue that statistics is the language of social justice. Almost all social issues can be described by the notable statistics surrounding the phenomenon. In his groundbreaking work *No BS (Bad Stats): Black People Need People Who Believe in Black People Enough Not to Believe Every Bad Thing They Hear About Black People*, Toldson (2019) explores how the use and misuse of statistics often lead to public policies and practices that negatively impact the Black community. However, these statistics (e.g., The National Assessment of Educational Progress) often come from national data collection efforts that highlight inequity, which lead to subsequent social justice initiatives. Hence, the data that describe inequity and injustice are translated to the public through statistical summaries, making statistics the language of social justice. The emergence of these and other data-driven social justice efforts has led to a sociopolitical shift in mathematics and statistics education.

In the present study, we sought to 1) identify what scholarly articles have been published from 2007 to 2023 in relation to teaching statistics for social justice, 2) identify the characteristics of those works published, and 3) identify how teaching statistics for social justice is described in the literature. Utilizing a scoping review, we were able to identify sixteen records that met the all-inclusive criteria established for the study. The scoping review results indicate that there is not only a dearth of literature focusing on teaching statistics for social justice but also limited empirical study of pedagogy, as evidenced by the larger number of non-empirical works on TS4SJ. Furthermore, through the lens of Lesser's (2007) conceptualization of TS4SJ, the findings reveal both alignment (e.g., issue driven) and divergence (e.g., community) from his original framework.

These results echo the findings of other syntheses of the literature related to teaching mathematics for social justice (Xenofontos et al., 2021). Xenofontos et al. (2021) conducted a systematic review of mathematics for social justice more broadly. Their synthesis identified 23 related records that examine a wide range of mathematics education contexts. Of these results, several of the records concluded that incorporating social justice into their mathematics classrooms had a positive impact on their students (Conway & Nguyen, 2020; Dacia et al., 2021; Lesser, 2017; ; Louie et al., 2022; Maloney, 2015; McCoy, 2008). The findings also included student growth, student empowerment, and a new respect for mathematics among students (Lesser, 2007; Louie et al., 2021; McCoy, 2008). In contrast, the present scoping review narrows the lens to TS4SJ and operationalizes this focus through Lesser's (2007) framework and alignment with GAISE standards. This distinction is important because our review systematically describes how statistics education has been conceptualized and enacted for social justice. By emphasizing both statistical literacy goals and the presence of TS4SJ in the literature, our work compliments and extends prior syntheses.

There were several characteristics of the published works that warrant further consideration. For instance, of the records identified, over half were non-empirical and only had implicit mentions of the terms set forth in the inclusion criteria. Alternatively, the empirical records displayed an even distribution of implicit and explicit mentions of the selected terms and phrases (Figure 4). The most common were *teaching mathematics for social justice* and *teaching statistics for social justice*, which closely resembled the search terms used to map the literature. The prevalence of implicit rather than explicit mentions suggests that authors may find it safer to frame social justice indirectly by weaving it into examples or curriculum descriptions without calling it out by name. This choice may reflect concerns about political resistance in educational settings or the lack of consistent frameworks for naming and evaluating TS4SJ. While implicit mentions allow for flexibility and broader acceptance, they also make it harder to identify and study TS4SJ in systematic ways.

Beyond terminology, the literature described TS4SJ in several ways. *Issue-driven* and *student empowerment* were among the most frequent descriptions used. In addition, TS4SJ was also described by the phrases: *reflect upon context* and *community*. Unexpectedly, *critical questions* did not emerge as having any connection to TS4SJ. This absence may reflect the political climate of education, where directly encouraging students to question systems of power and inequity can be seen as controversial. As a result, authors may have chosen to emphasize less politically charged ideas, such as empowerment or community, which are more widely accepted in schools. Future research should explore how TS4SJ can effectively support students in engaging with critical questions, even within politically sensitive environments and periods.

Finally, when reviewing the distribution of participants in the records, the data did not sway one way or the other. There was an even spread of results among pre-service teachers, in-service teachers, K-12 students, post-secondary students, and none. K-12 students were the front-runners, with five records naming this group as participants. When looking at the age groups considered in each study, grades 9-12 and post-secondary students accounted for almost three-fourths of the participants.

Additionally, the results of our review revealed four recurring themes that characterize how TS4SJ has been taken up in the literature. These themes highlight both the breadth of approaches to TS4SJ and the ongoing lack of coherence in how it is conceptualized and studied. The first theme, *incorporating social justice into statistics education*, reflects a growing recognition that statistics curricula can be reshaped to address societal issues alongside technical skills (e.g., Dacia et al., 2021). This aligns with Lesser's (2007) call to include social justice issues into statistics content. This integration shows the potential of TS4SJ to enrich learning, yet most examples remain at the conceptual level and provide little evidence of impact on students. One possible reason for this gap is that developing and testing fully integrated TS4SJ curricula requires time, resources, and institutional support, which are often limited in practice.

The second theme, *using social justice data to teach statistics*, emphasizes the value of authentic, real-world datasets for engaging students in meaningful analysis (e.g., Loux & Gibson, 2019). The second theme aligns with Lesser's (2007) emphasis on using authentic, meaningful data while developing critical statistical literacy. This approach encourages both statistical literacy and critical thinking, but many examples are context-specific and leave open questions about how such data-driven approaches can be scaled across classrooms. The dominance of secondary-level contexts in this body of work may reflect the availability of justice-related datasets that align with secondary standards and the emphasis on engaging adolescents in civic issues. However, this also reveals a gap. Little is known about how TS4SJ could be taken up in elementary or postsecondary settings, where the developmental goals and curricular constraints differ.

The third theme centers on *teaching statistics for social justice in specific contexts*, often through project-based or experiential learning such as service-learning environments or community projects (e.g., Maloney, 2015). This theme aligns with Lesser's (2007) idea that students should see statistics connected to real communities and problems. Additionally, these approaches demonstrate how contextualized learning can make statistical concepts more relevant and engaging, though they also raise questions about transferability outside of specialized projects. The prevalence of context-specific studies may point to the experimental nature of this work: educators and researchers often pilot TS4SJ in small, localized settings where they have freedom to innovate, but these designs have yet to be scaled or systematically assessed.

The fourth theme focuses on *developing critical statistical literacy for social justice*, where students are encouraged to question how data are collected, represented, and interpreted (e.g., Cannon, 2022). This theme reflects Lesser's (2007) emphasis on critical reflection and has the most transformative potential of TS4SJ, yet it is also the least developed, with few studies showing systematic ways to build or assess these skills. The limited attention to critical statistical literacy may be linked to the dominance of implicit rather than explicit approaches to TS4SJ in the literature. When social justice is addressed implicitly, it is often woven into data or examples without unpacking the broader social implications. While this can make TS4SJ feel seamlessly integrated, it also risks minimizing critical discussions about power, equity, and data ethics.

Taken together, the four themes show that teaching statistics for social justice is still developing and uneven. Themes one and two focus on curriculum, while themes three and four highlight pedagogy. This suggests the field has grown along two separate but not well-connected paths. The use of social justice content and authentic datasets shows a shift toward statistics as a tool for civic engagement. At the same time, the reliance on context-specific and often implicit approaches shows a lack of clear frameworks for design and evaluation. Current approaches are flexible and allow for innovation, but they are also fragile because there is little agreement on how to measure impact. Across all themes, there is limited evidence of how TS4SJ influences student learning, critical thinking, or teacher preparation. Future research should not only describe practices but also examine why certain approaches dominate, how they can be adapted across contexts, and what long-term effects

they have on both students and teachers. These patterns show that the four themes are not only descriptors of current work but also indicators of where the field needs to grow.

Implications

The present scoping review provides a comprehensive overview of the current state of TS4SJ literature and offers valuable insights into its characteristics, trends, and implementation. The identified implications highlight opportunities for future research, curriculum development, and pedagogical innovation in the field of teaching statistics for social justice. By addressing these implications, educators and researchers can contribute to the advancement of TS4SJ, ultimately fostering a more equitable and socially conscious approach to statistics education. The results of this scoping review shed light on several critical implications for the field of teaching statistics for social justice (TS4SJ). These implications are outlined below:

1. *Researchers should be attentive to TS4SJ publication trends and should prioritize empirical investigations to provide evidence-based insights into the impact of TS4SJ on student learning and social justice awareness.* One of the notable findings of this scoping review is the temporal distribution of TS4SJ publications. The peak in publications between 2015 and 2020 suggests a growing interest in TS4SJ within the last decade. This trend is indicative of the evolving landscape of education and the increasing recognition of the importance of social justice in teaching statistics. There is also a noticeable absence of empirical research in the TS4SJ literature. Over half of the included records were non-empirical, and there was a dearth of traditional quantitative inquiry. This highlights a pressing need for more empirical studies that assess the effectiveness and outcomes of TS4SJ pedagogical approaches.
2. *Researchers should consider the benefits of explicitly mentioning or, more importantly, operationalizing TS4SJ in their work.* This will promote a clearer understanding of the approach, its objectives, and how it can be measured with validity and reliability. The prevalence of implicit descriptions of TS4SJ in curriculum and instructional materials is noteworthy. While TS4SJ principles are often embedded in educational practices, the lack of explicit representation hinders the growth of the field.
3. *Researchers and educators should explore ways to adapt TS4SJ principles to meet the needs of diverse educational contexts.* The majority of TS4SJ tasks in the literature have a secondary school focus. While this suggests that TS4SJ is gaining traction in K-12 education, there is room for expanding its application to elementary and post-secondary education levels. The inclusion of various participant groups, including in-service teachers, pre-service teachers, K-12 students, and post-secondary students, indicates that TS4SJ is not confined to a specific educational level or context. However, more research is needed to explore the unique challenges and opportunities associated with each group. Understanding the needs and perspectives of different participants can inform tailored TS4SJ interventions.
4. *The identification of four major themes related to TS4SJ implementation provides a roadmap for educators and researchers.* Incorporating social justice into statistics education, using social justice data to teach statistics, teaching statistics for social justice in specific contexts, and developing critical statistical literacy for social justice are all areas that warrant further exploration and development, as noted in the scoping review results. The four trends, in particular, have unique and potentially transformative implications for mathematics education. First, incorporating social justice into statistics education highlights a growing interest in modifying traditional statistics curricula to include social justice content. This suggests that educational institutions should consider the integration of TS4SJ principles into their curriculum development processes. This will ensure that future statisticians and educators are equipped with a social

justice perspective. Second, using social justice data to teach statistics underscores the importance of using real-world data to engage students in meaningful statistical learning experiences. This approach not only enhances statistical literacy but also encourages critical thinking about social justice issues. Educators should explore diverse datasets and methods for incorporating such data into their teaching. Third, teaching statistics for social justice in specific contexts emphasizes the value of project-based and experiential learning. Finally, developing critical statistical literacy for social justice highlights the need to prepare students to question how data are constructed, represented, and interpreted. This approach positions students as critical consumers of quantitative information and fosters deeper engagement with both statistics and social justice. Together, these approaches allow students to apply statistical concepts to real-world problems and immerse themselves in social justice issues. Educators should consider the benefits of contextualized pedagogical environments to foster deeper engagement with TS4SJ.

Limitations

While the scoping review helped to identify the literature on teaching statistics for social justice, it does have limitations. Arksey and O'Malley (2005) noted in their scoping studies that scoping reviews do not allow for the synthesis of literature. In other words, this scoping review provided a descriptive overview of the available literature but did not assess the quality or relative weight of each study (Arksey & O'Malley, 2005). A deep analysis of the collected data was not possible for this study. Another limitation of this study is the possibility of missing relevant records that should have been included in the review (Pham et al., 2014). The selected databases and time constraints may have contributed to missing relevant records.

Conclusion

This scoping review, grounded in Lesser's (2007) framework for TS4SJ, reveals a dynamic research landscape in statistics education for social justice. The literature search uncovered a recent surge in TS4SJ publications, signifying interest in this critical line of inquiry in mathematics education. Upon examining the methodology, it became evident that over half of the publications were non-empirical in nature. This suggests a significant gap in the empirical foundation of TS4SJ. This gap in the empirical literature raises critical questions about the pedagogical impact and effectiveness of TS4SJ. Additionally, one distinctive feature of the results is the prevalence of implicit descriptions of TS4SJ, often intertwined rather than explicitly defined and unpacked in the included studies. However, one could argue that this implicit portrayal of TS4SJ underscores the seamless integration of social justice principles into mathematics and statistics education. This trend was evident in non-empirical publications that more frequently adopt the term "Teaching Statistics for Social Justice," highlighting the evolution of the discourse surrounding TS4SJ.

Regarding praxis, the diversity of participants in TS4SJ initiatives reflects its potential to engage learners across various educational levels, from in-service teachers to K-12 and post-secondary students. Yet, the predominance of TS4SJ tasks within secondary education is a noteworthy trend, because it could suggest that the complexities of incorporating social justice into mathematics and statistics education are most problematic in elementary and post-secondary settings due to the practical and political challenges that one must navigate to engage these two groups in TS4SJ tasks. However, this complexity could be addressed by exploring the themes of the present scoping review related to TS4SJ implementation. Our review revealed four major themes that shed light on TS4SJ implementation. "Incorporating Social Justice in Statistics Education" underscores the growing movement to infuse social justice content into traditional statistics curricula. Alternatively, "Using

Social Justice Data to Teach Statistics" reveals the use of real-world data tied to social justice issues as a pedagogical strategy. "Teaching Statistics for Social Justice in Specific Contexts" reflects an exploration of TS4SJ within project-based, contextualized environments, offering a rich tapestry of experiential learning. Finally, "Developing Critical Statistical Literacy for Social Justice" emphasizes that equipping learners with critical statistical literacy skills is pivotal.

In conclusion, this scoping review unravels the multifaceted dimensions of TS4SJ, demonstrating its growing significance in the field of education. While the field of statistics education has embraced Lesser's (2007) emphasis on nontrivial contextualization (i.e., themes 1 and 2) and reflection upon socio-political context (i.e., theme 3), critical gaps remain in implementing his vision for critical questioning and student 'talk back' or action-taking. Moreover, the stark gap in empirical research, juxtaposed with the diverse approaches to TS4SJ implementation, presents both challenges and opportunities. As TS4SJ continues to evolve, interdisciplinary collaboration and rigorous empirical inquiry must guide its trajectory, ensuring its enduring impact on the landscape of social justice in mathematics education.

The authors received no financial support for the research, authorship, and/or publication of this manuscript

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Gaining Confidence: Increasing Elementary Mathematics Teaching Self-Efficacy Through Coaching

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Abstract

Mathematics coaching is a professional development intervention being used to improve student learning. As student achievement has been linked to teacher self-efficacy, this study investigated whether an individual math coaching program for elementary teachers improved their mathematics teaching self-efficacy. Personal Mathematics Teaching Efficacy was improved in a statistically significant way over the ten-week intervention, but Mathematics Teaching Outcomes Expectancy did not increase significantly. Interviews indicated that teachers sought and received validation for their teaching from the coaches, likely contributing to the increase in self-efficacy. Schools and districts could consider implementing coaching to improve teacher self-efficacy.

Keywords: Instructional coaching, Math Teaching Efficacy, Elementary Mathematics, Teacher Professional Learning

Introduction

Beliefs about one's capability as a learner of mathematics influence math teacher learning and teaching (Bandura, 1986b). Teachers' self-efficacy around math instruction has been shown to positively impact students' achievement and confidence in mathematical learning (e.g. Chang, 2015). Improving teachers' self-efficacy and mathematics teaching efficacy has the potential to increase student achievement in mathematics. Consequently, districts have increased their investments in high-quality professional learning opportunities targeting teacher self-efficacy and mathematics teaching efficacy to improve teachers' self-efficacy in mathematics.

Instructional coaching is one form of professional learning designed to support teacher effectiveness in teaching literacy, and, increasingly, in mathematics teaching. Instructional coaching has been linked to improved teacher confidence and teacher self-efficacy (TSE). When implemented effectively, instructional coaching embeds professional learning into teachers' daily practice. Instructional coaching, when done well, is an opportunity to embed professional learning in educators' day-to-day work. With a minimal outlay of resources, effective instructional coaching models build the capacity of teachers, improve teacher retention, and raise student achievement.

While the benefits of instructional coaching have been explored as a school improvement strategy, fewer studies investigate instructional coaching related to mathematics instruction and elementary mathematics teachers' self-efficacy. This study connects these two bodies of research on instructional coaching with research on teacher self-efficacy and applies them in the context of mathematics teaching. More specifically, this study examines the impact of an instructional coaching cycle on elementary school teachers' reported mathematics teaching self-efficacy and their reported mathematics teaching outcomes expectations.

Theoretical and Conceptual Framework

The study uses Bandura's (1977) theory of self-efficacy as a theoretical pillar. As researchers, we adopted the following theory of action related to this study: High levels of teacher self-efficacy and mathematics teaching efficacy impact student learning. If math teachers engage in a cycle of intentional instructional coaching around mathematics instruction, math teachers' reported levels of mathematics teaching efficacy will improve. Improving educators' mathematics teaching efficacy through instructional coaching may positively influence students' mathematical learning.

Self-efficacy

For our study, we draw upon Bandura's (1977) theory of self-efficacy which highlights the power of belief in one's capabilities to shape behavior and achieve success. Bandura (1977) identifies four factors as contributing to self-efficacy: 1) prior performance – how one performed previously on a similar task; 2) vicarious performance – seeing how others perform at the same task; 3) verbal persuasion – encouragement from others; and 4) physiological cues – nervousness or excitement.

Bandura's theory of self-efficacy is an extension of Rotter's (1966) theory of locus of control. In this theory of locus of control, Rotter contends that individuals have different understandings and beliefs about their ability to influence outcomes: some believe outcomes are out of their control, while others believe themselves to be in control of outcomes. In this view, the locus of control describes a person's beliefs about their influence over outcomes. Rotter distinguishes between an *internal locus of control* and an *external locus of control* (Rotter, 1966). People with an internal locus of control believe their actions determine outcomes whereas those with an external locus of control attribute outcomes to external factors.

Bandura extends Rotter's work by theorizing that the extent to which one believes oneself to be in control of outcomes is a function of one's capabilities (1977, 1986a, 1997). When applied to education, if an intervention can increase a teacher's capacity to believe themselves capable and thus have the locus of control over some domain-specific tasks such as multiplying multi-digit numbers, then the teacher is more likely to also believe they are in control of individual student learning of that task. In essence, self-efficacy is a construct that represents a measure of teachers' beliefs about their ability to be in control of outcomes (Bandura, 1977, 1986a, 1997).

Teacher self-efficacy influences teachers' thoughts and emotions, which in turn enable or inhibit actions (Gavora, 2010). Gavora (2010) also notes that differences in teacher effectiveness may be largely the result of teaching self-efficacy. Greater self-efficacy catalyzes positive thoughts and emotions which enable actions: teachers with high levels of self-efficacy are more likely to persist in the face of challenges and be less fatalistic about their ability to overcome such challenges (Gibson & Dembo, 1984). Similarly, teachers with strong self-efficacy are more likely to persist when trying something new or when implementing new instructional strategies and pedagogical skills (Holzberger et al., 2013).

Under this construct, students would presumably benefit from teachers with higher levels of self-efficacy. That is, students would benefit from learning from teachers who believe themselves to be in control of their fates, who are more persistent in overcoming challenges, and who are more flexible in adapting new skills and strategies into their teaching practice (Tschannen-Moran & Woolfolk Hoy, 2001; Woolfolk Hoy et al., 2009; Zee & Koomen, 2016).

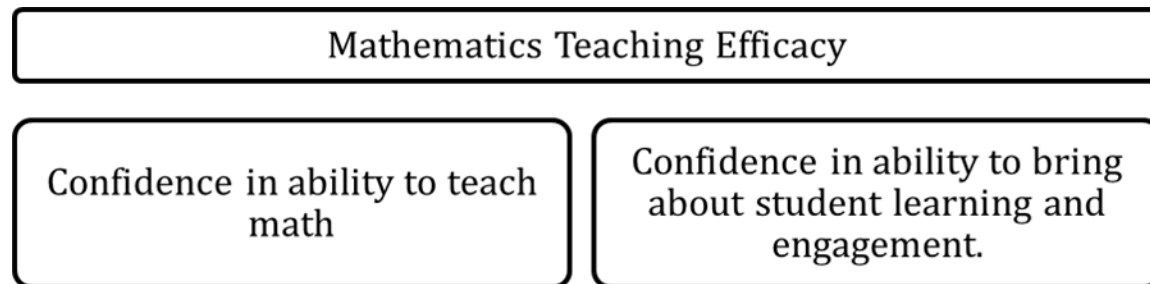
Teachers' Math Self-efficacy and Mathematics Teaching Efficacy

Educational researchers claim that a teacher's self-efficacy has a significant positive impact on student learning (e.g., Hickman & Sherman, 2019; Klassen & Tze, 2014). We turn now to address the research that examines self-efficacy and teaching efficacy through a lens of mathematics and mathematics instruction.

Mathematics self-efficacy is a person's belief about their ability to do, perform, or learn mathematics (Bandura, 1986b). Similarly, mathematics teaching efficacy is a teacher's belief about their ability to teach mathematics, and in particular, a belief in their ability to bring about student learning and engagement (Tschannen-Moran & Woolfolk Hoy, 2001). See Figure 1 for additional details. Importantly, mathematics teaching efficacy goes beyond teacher competence in that it encompasses not only knowledge and skills but the ability to enact knowledge and skills in practice (Zuya et al., 2016). Theoretically, an educator with high mathematics teaching efficacy would have an internal locus of control and should feel more in control of outcomes (i.e., student learning and engagement).

Figure 1

Components of Mathematics Teaching Efficacy



While this study focuses only on mathematics teaching efficacy, teachers' own math self-efficacy is positively correlated with teachers' mathematics teaching efficacy. Teachers who are confident in their own mathematical abilities are likely to believe they can directly impact students' mathematical learning (Bates et al., 2011). There is a strong relationship between mathematics self-efficacy and mathematics achievement (Siegle & McCoach, 2007). Similarly, in a study by Stevens et al. (2004), students assigned to teachers with high self-efficacy reported higher perceptions of mathematical ability in their final years of elementary school and middle school. Students paired with teachers with high self-efficacy perceived math as less difficult and expected to do better at math in the future than those students paired with teachers with lower self-efficacy (Stevens et al., 2004). In contrast, students who had been paired with high efficacious teachers in elementary school but who were paired with lower efficacious teachers in middle school, experienced declines in their perceived mathematical abilities; they judged the content as more difficult than their peers (Stevens et al., 2004). In general, lower achieving students were more sensitive to the efficacy level of their teachers. This suggests that pairing high efficacy teachers with lower achieving students in math instruction might result in improved math achievement for those students (Stevens et al., 2004). Additionally, teachers' teaching self-efficacy impacts teachers' choices of instructional strategies, pedagogical tools, and impacts the classroom climate, which in turn influences student learning (e.g., Siegle & McCoach, 2007). In an additional study, Xenofontos and Andrews (2020) use qualitative semi-structured interviews to probe teachers' understandings of self-efficacy around themes related to past experiences with mathematics, resilience, and mathematical competence. The authors highlight

the complexity of self-efficacy and its measurement. Thus, improving teachers' math self-efficacy and mathematics teaching efficacy is likely to improve students' math self-efficacy and overall achievement in mathematics.

Instructional Coaching

Schools have embraced instructional coaching as a model for professional learning. District leaders have recognized that one-off professional development days and professional learning workshops are ineffective models for sustaining improvement in teaching and learning (Ball & Cohen, 1999). Instead, investing in job-embedded interventions such as instructional coaching may produce more effective educators and stronger student outcomes. Investment in job-embedded interventions such as instructional coaching rather than standalone professional learning workshops may lead to more effective educators and increased outcomes for students. A meta-analysis by Kraft et al. (2018) finds causal evidence of the outsized impact of coaching on student achievement. Additionally, coaching is more economical when compared to traditional teacher development programs.

White et al. (2015) built on the work of Hanft et al. (2004) in identifying a conceptual framework for instructional coaching. They identified the following progression for successful coaching: joint planning between the coach and teacher; opportunity for the teacher to analyze or practice the new skills and strategies identified in the plan; the opportunity for the coach to observe the teacher, the teacher to observe the coach, or both; opportunity for the teacher to reflect; feedback from the coach; and reflective discussion between the coach and teacher. They argue that these stages provide the strongest opportunity for success with an instructional coaching program. While the progression should be followed for all teachers, the actual skills and strategies identified will be individualized for each teacher, based on their personal skills and needs (Wang, 2017).

A robust research base deems instructional coaching a high impact instrument for instructional change (e.g., Coburn & Woulfin, 2012; Desimone & Pak, 2017; Kraft et al., 2018; Russell et al., 2020; Woulfin & Rigby, 2017). In fact, Tschannen-Moran & McMaster (2009), found that instructional coaching designed to support mastery experiences had the strongest impact on teacher self-efficacy of four professional development models studied. Instructional coaching embeds professional learning opportunities into the day-to-day work of teachers (Heineke, 2013; Kraft et al., 2018). It also mediates the relationship between policy and classroom practice (Coburn & Woulfin, 2012). As coaches often work directly with teachers to support educator learning and shift classroom practice, instructional coaching can increase teacher efficacy to promote students' learning (Kraft et al., 2018; Russell et al., 2020; Woolfolk Hoy & Spero, 2005).

Districts approach coaching differently and with considerable variation (Hannan & Russell, 2020). Some districts view coaching as a lever for compliance (Coburn & Woulfin, 2012), or view coaches as thought partners, mentors, and collaborators (Sailors & Price, 2015). In addition to the function of coaching, the mode of coaching also varies considerably. Some coaching models embed coaches at one school and in teachers' classrooms, while other models envision coaching as an intervention for collective school improvement (Gibbons et al., 2017). Others have coaches travel throughout the district or approach coaching virtually. Still others prioritize coaching for teachers with a certain number of years of experience or in specific academic disciplines. Despite the variation in the model, using instructional coaching to build teacher efficacy; when the elements of a good coaching model are implemented, can cultivate success for teachers and students (Althausen, 2015; Marzano & Simms, 2014; Woolfolk Hoy & Spero, 2005).

When embarking on an instructional coaching cycle, there are critical elements to good instructional coaching models (Eastman, 2019). First, the coach/teacher relationship must be built on trust. Second, partners must develop confidence and identity as coaches and teachers. Third, the

collaborative model must scaffold experiences for the teacher based on the coach's ability to actively listen, ask reflective questions, and provide timely and appropriate feedback during the instructional coaching cycle. Additionally, in another study, three specific coaching actions - modeling, practice, and feedback - but especially practice during the coaching cycle, led to increased student achievement (Glover et al., 2023).

Similar to other instructional coaches, the role of mathematics coaches in instructional reform and institutional change continues to evolve (Hopkins et al., 2016). Mathematics coaches, and especially mathematics coaches with training and experience, positively affect student mathematics achievement over time (Campbell & Malkus, 2011). In Gibbons and Okun's (2023) study of a mathematics coaching routine termed *Teacher Time Out*, dedicated time to address complex pedagogical moves in-the-moment developed math teachers' collaborative inquiry into their teaching practice and enhanced equitable and ambitious teaching practices by facilitating mathematics discussions amongst students.

Instructional Coaching and Self-Efficacy

When identifying coaching as the professional development model which most significantly affected self-efficacy, Tschannen-Moran & McMaster (2009) theorized how the coaching elements were related to Bandura's four elements of self-efficacy. Verbal persuasion from a coach could encourage a teacher to try new strategies or activities, despite the effort needed. By watching a coach model a lesson, a teacher could have the vicarious experience of success with a strategy. This was found most impactful if the teacher felt their capabilities to be similar to those of the coach. Having mastery experiences early in the coaching process was seen as critical to the growth of self-efficacy, and early failures were difficult to overcome. Having the opportunity to practice skills in a supportive setting allowed for a reduction in the fear of failure, which align with physiological cues of fear and nervousness.

Several studies showed an increase in self-efficacy when participants took part in either a coaching program or coaching training. In these studies, there was a focus on observation of modeled lessons, instructional support, and feedback (Goker, 2006; Panfillo-Padden, 2014; Entwistle & Rees-Davies, 2025). Pearson (2016) similarly found that the coaching activities of modeling instruction and classroom management strategies led to increases in teacher self-efficacy in student engagement and instructional practices. Walsh et al. (2020), mirroring the findings of Eastman (2019), note that the coaching process needs to be built on a collaborative model that builds trust between the coach and teacher and allows both parties to grow in their skills and confidence.

Few studies were found that addressed instructional coaching and self-efficacy in mathematics. Fewer still measured mathematics teaching self-efficacy in a quantitative manner. Bruce and Ross (2008) found that peer-coaching among elementary teachers improved their self-efficacy for teaching mathematics, but the data were qualitative in nature. Vicarious experiences, through observing other teachers, were noted to be a strong contributor to the increased self-efficacy; as they were able to more confidently implement new strategies after seeing them modeled. Participants also related that their students' enthusiasm and improvement contributed to increased self-efficacy.

Several recent dissertations have also examined the link between mathematics coaching and self-efficacy (Barnes, 2025; Rosato, 2019; Strong, 2021). In a study of high school mathematics teachers, Barnes (2025) did find a significant increase in self-efficacy after a coaching cycle. Strong (2021), who used a version of the Mathematics Teacher Efficacy Beliefs Instrument (MTEBI) that focused specifically on mathematical practices, reported increased self-efficacy for K-2 teachers after a six-week coaching cycle. This study did not, however, present quantitative data to support the

qualitative analysis of improved confidence. Rosato's study (2019) looked at coaching across multiple subjects, including mathematics, for elementary teachers. Using the Teachers' Sense of Efficacy Scale, she did not find a significant increase in self-efficacy, though coaching did impact teacher instructional practices. As so few studies have examined the impact of mathematics instructional coaching on mathematics teaching self-efficacy, this study may help to fill that gap.

Statement of the Problem

Strong mathematics self-efficacy and mathematics teaching efficacy are essential constructs that positively influence teachers' attitudes and behaviors toward mathematics teaching. Teachers with a high sense of mathematics self-efficacy and mathematics teaching efficacy are thought to be effective math educators. Instructional coaching, when done well, has been shown to be an effective form of job-embedded professional learning. As such, instructional coaching holds potential in supporting increases in teaching efficacy. Teachers need professional learning opportunities that enhance their capacity for effective mathematics instruction. This study seeks to answer the following research question: To what degree did a ten-week coaching cycle improve the mathematics teaching efficacy of elementary teachers?

Methodology

This study employed a convergent mixed-methods design which combined survey data with qualitative interviews (Creswell & Plano Clark, 2011). This allowed us to elicit contextualized insights from participants' experiences, perceptions of the coaching cycle, and offset some of the cautions from Xenofontos and Andrews (2020) related to quantitative analyses of self-efficacy. All methods and materials were submitted to the Institutional Review Board (IRB) prior to initiating any steps in the study. Additionally, our research was reviewed by the IRB and determined to be exempt (45 CFR 46). Since this research involved partners in a school district, the research team also received a letter of support for the research study from the school district. Informed consent/assent from all participants was obtained.

Participants

Individuals (n=17) were purposefully selected based on their participation in the coaching cycle. Participation in the study was entirely voluntary, and all participants were informed of their rights, including the right to withdraw from the study at any time without consequence.

Participants were classroom teachers in two K-6 elementary schools in a regional school district who participated in a required ten-week mathematics coaching cycle. Half participated during the second quarter of the school year and the other half during the third quarter. Although participation in the study was optional, all teachers in the two coaching cycles agreed to participate. The coaches were former teachers in the district who were identified as having strong mathematics skills and were hired into the coaching roles. In this document, all participants have been assigned pseudonyms.

Description and Format of the Coaching Cycle

After identifying weaknesses in their math program, the district had recently implemented a new mathematics curriculum and concurrently implemented this mathematics coaching program. One primary goal of the coaching program was to help teachers implement the program with fidelity. Each teacher worked either one-on-one with one of two math instructional coaches, or with

a co-teacher and one of the coaches. At the beginning of the coaching cycle, the coach and teacher(s) collectively surfaced one or more goals to work on over the next ten weeks. These goals are described in the findings.

The coach and teacher(s) were scheduled to meet at least once every six days for a common planning time. Weather, absence of the coach or teacher, and other professional development obligations sometimes impacted meeting times. Some teachers chose to meet more frequently with the coaches, as their schedules permitted.

During this dedicated planning time, the coaches and teachers collaboratively examined curriculum, developed lesson plans, or otherwise worked to further the goal(s) chosen by the teacher. In addition, coaches observed classes, taught portions of classes to model pedagogical strategies, and led group work to help address classroom needs. Elaboration on the coaching practices can be found in the findings.

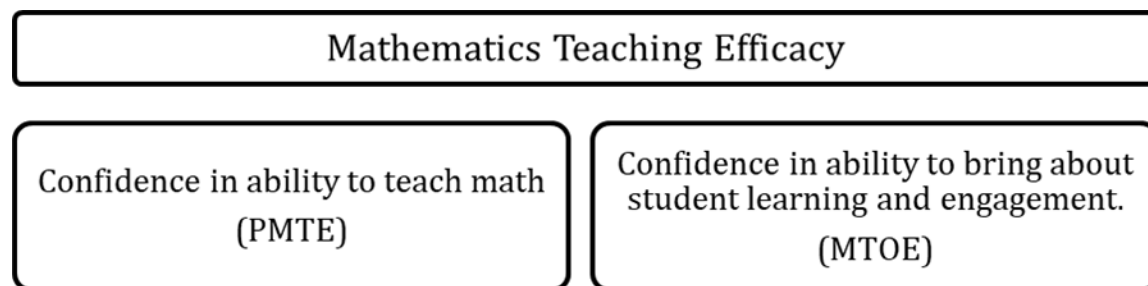
Data Collection

Pre/Post Survey Instrument

Prior to the beginning of the coaching cycle and at the end of the coaching cycle, each teacher completed the Mathematics Teacher Efficacy Beliefs Instrument (MTEBI), a twenty-one-item survey developed by Huinker and Enochs (1995), with a five-point Likert scale. The MTEBI has been shown to measure two constructs, Personal Mathematics Teaching Efficacy (PMTE), which indicates how capable the teachers feel about teaching mathematics at the elementary school level, and Mathematics Teaching Outcomes Expectations (MTOE). The MTOE indicates how much impact elementary teachers believe they have on the learning outcomes of their students (Huinker & Enochs, 1995; Enochs et al., 2000). Figure 2 illustrates how the two components relate to the earlier discussion of mathematics teaching self-efficacy.

Figure 2

Relationship of MTEBI constructs to Mathematics Teaching Efficacy



The MTEBI was initially designed to study the self-efficacy of pre-service teachers but, as the types of questions asked addressed the beliefs we were interested in exploring; we adapted some questions to make them more applicable to in-service teachers (Figure 3).

Figure 3*MTEBI Items (Adapted)*

1. When a student does better than usual in mathematics, it is often because the teacher exerted a little extra effort. (MTOE)
2. I continually find better ways to teach mathematics. (PMTE)
3. Even if I try very hard, I will not teach mathematics as well as I will most subjects. (PMTE)*
4. When the mathematics grades of students improve, it is often due to their teacher having found a more effective teaching approach. (MTOE)
5. I know how to teach mathematics concepts effectively. (PMTE)
6. I am not very effective in monitoring mathematics activities. (PMTE)*
7. If students are underachieving in mathematics, it is most likely due to ineffective mathematics teaching. (MTOE)
8. I generally teach mathematics ineffectively. (PMTE)*
9. The inadequacy of a student's mathematics background can be overcome by good teaching. (MTOE)
10. When a low-achieving child progresses in mathematics, it is usually due to extra attention given by the teacher. (MTOE)
11. I understand mathematics concepts well enough to be effective in teaching elementary mathematics. (PMTE)
12. The teacher is generally responsible for the achievement of students in mathematics. (MTOE)
13. Students' achievement in mathematics is directly related to their teacher's effectiveness in mathematics teaching. (MTOE)
14. If parents comment that their child is showing more interest in mathematics at school, it is probably due to the performance of the child's teacher. (MTOE)
15. I find it difficult to use manipulatives to explain to students why mathematics works. (PMTE)*
16. I am typically able to answer students' questions. (PMTE)
17. I wonder if I have the necessary skills to teach mathematics. (PMTE)*
18. Given a choice, I would prefer not to invite the principal to evaluate my mathematics teaching. (PMTE)*
19. When a student has difficulty understanding a mathematics concept, I am usually at a loss as to how to help the student understand it better. (PMTE)*
20. When teaching mathematics, I usually welcome student questions. (PMTE)
21. I do not know what to do to turn students on to mathematics. (PMTE)*

* Indicates that the item is reverse-coded.

Semi-Structured Teacher Interviews

In addition, each teacher was interviewed at the end of the coaching cycle, using a semi-structured interview protocol, co-designed by the researchers and the coaching team (Figure 4). The goal was to better understand teachers' perspectives of the coaching process. Interviews were conducted using video technology and recorded with participant permission. When recording was not possible, the interviewer took detailed notes. All interviews were transcribed and verified for accuracy.

Figure 4

Semi-Structured Interview Questions

COACHING

1. Please share a bit about how you approach math instruction in your classroom.
2. Can you talk about how you engaged with the recent cycle of math instructional coaching?
3. In what ways do you think your approach to teaching mathematics has changed after the math instructional coaching cycle? Can you talk about specific changes you've made to your math instruction based on the coaching you received?
4. Can you talk a bit about the goal you set with your instructional coaches in this coaching cycle? Do you feel as though you made progress toward the goal you established with your coaches?

TEACHING

5. What are your goals for your students when it comes to mathematics?
6. What types of instructional strategies do you find to be particularly effective for teaching mathematics?

SELF

7. Now, would you mind speaking a bit about yourself as a learner:
 - a. How did you engage with math instruction as a learner?
 - b. What did "learning" and "success" in mathematics look and feel like for you as a student?
8. How confident are you in your ability to teach mathematics in ways that might be different from the ways you learned?

Data Analysis

To look for any significant changes in teacher self-efficacy, one-tailed, paired sample *t*-tests were run on the MTEBI data to compare the pre- and post-item scores for PMTE, MTOE, and each individual item.

To explore how the coaching process might be linked to any changes in teacher self-efficacy, the research team, consisting of three primary researchers, manually coded the interview transcripts using thematic coding (Braun & Clark, 2006). Both coaching goals and the coaching process were examined to identify how the coaching program was implemented for each participant. The interviews were further analyzed to identify salient patterns and recurring themes in the responses that might offer insight as to why changes in self-efficacy were or were not found.

Findings

The evaluation of the data from this instructional coaching cycle revealed a range of insights. Survey findings indicate significant increases in Personal Mathematics Teaching Efficacy (PMTE), but not

in Mathematics Teaching Outcomes Expectancy (MTOE). What follows is a more detailed description of these findings along with supporting evidence from the interviews.

MTEBI Survey Findings

Personal Mathematics Teaching Efficacy

From the analysis of the MTEBI data, PMTE increased by a statistically significant amount (Table 1). Within the PMTE construct, six of the thirteen indicators increased significantly. These items included items numbered 6, 11, 16, 16, 19, and 20.

Table 1

Personal Mathematics Teaching Efficacy Results

Personal Mathematics Teaching Efficacy (PMTE)	Pre-Coaching Mean	Post-Coaching Mean	Δ	p-Value
Overall PMTE (Range is 13-65)	54.15	57.09	2.94	0.004*
For questions below, 5=strongly agree				
2. I continually find better ways to teach mathematics.	4.21	4.53	0.32	0.06
5. I know how to teach mathematics concepts effectively.	4.00	4.24	0.24	0.08
11. I understand mathematics concepts well enough to be effective in teaching elementary mathematics.	4.06	4.74	0.68	0.0004*
16. I am typically able to answer students' questions.	4.41	4.62	0.21	0.02*
20. When teaching mathematics, I usually welcome student questions.	4.59	4.76	0.18	0.04*
For questions below, 5=strongly disagree				
3. Even if I try very hard, I will not teach mathematics as well as I will most subjects.	4.35	4.12	-0.24	0.15
6. I am not very effective in monitoring mathematics activities.	4.00	4.29	0.29	0.03*
8. I generally teach mathematics ineffectively.	4.29	4.41	0.12	0.29
15. I find it difficult to use manipulatives to explain to students why mathematics works.	4.29	4.35	0.06	0.36
17. I wonder if I have the necessary skills to teach mathematics.	3.88	4.41	0.53	0.01*
18. Given a choice, I would prefer not to invite the principal to evaluate my mathematics teaching.	4.06	4.12	0.06	0.41
19. When a student has difficulty understanding a mathematics concept, I am usually at a loss as to how to help the student understand it better.	4.12	4.44	0.32	0.03*
21. I do not know what to do to turn students on to mathematics.	3.88	4.06	0.18	0.21

* $p < 0.05$

Mathematics Teaching Outcomes Expectancy

Overall Mathematics Teaching Outcomes Expectancy (MTOE) did not change significantly (Table 2). Only one of the eight items that comprised the MTOE construct, item number 1, changed significantly.

Table 2

Mathematics Teaching Outcomes Expectancy Results

Mathematics Teaching Outcomes Expectancy (MTOE)	Pre-Coaching Mean	Post-Coaching Mean	Δ	p-Value
Overall MTOE (Range is 8-40)	25.91	26.24	0.32	0.36
5=Strongly Agree				
1. When a student does better than usual in mathematics, it is often because the teacher exerted a little extra effort.	3.00	3.53	0.53	0.04*
4. When the mathematics grades of students improve, it is often due to their teacher having found a more effective teaching approach.	3.85	3.65	-0.21	0.18
7. If students are underachieving in mathematics, it is most likely due to ineffective mathematics teaching	2.09	2.06	-0.03	0.46
9. The inadequacy of a student's mathematics background can be overcome by good teaching.	3.71	3.59	-0.12	0.29
10. When a low-achieving child progresses in mathematics, it is usually due to extra attention given by the teacher.	3.09	3.35	0.26	0.08
12. The teacher is generally responsible for the achievement of students in mathematics.	3.76	3.71	-0.06	0.37
13. Students' achievement in mathematics is directly related to their teacher's effectiveness in mathematics teaching.	3.06	3.18	0.12	0.25
14. If parents comment that their child is showing more interest in mathematics at school, it is probably due to the performance of the child's teacher.	3.35	3.18	-0.18	0.24

* $p < 0.05$

Coaching Goals and Activities

Each participant reported setting at least one goal with their mathematics coach and some noted more than one goal. In a few cases, the goal changed during the process, as either the participant or coach noted a new need. Coaching activities were well-aligned to the goals, as shown in Table 3.

Table 3*Coaching Goals and Activities*

Participant	Coaching Goal(s)	Coaching Activities
Ms. Adams	Differentiation	Coach gave assistance modifying materials for special education students.
Ms. Brown	Technology for differentiation and reteaching; understanding strategies and expectation	Used coach as a reference for both student concerns and for understanding content and strategies.
Ms. Carey	Technology for differentiation and reteaching	Coach helped with understanding the curriculum; learning to use the technology for differentiation and reteaching, including using data.
Ms. Dalton	Pacing	Coach pushed into classroom - observed, took notes, met to discuss. Gave strategies for how to fit it all in, provided some resources to help.
Ms. Evans	Unit planning; differentiation; fostering student independence	Coach provided guidance on differentiation and scaffolding, which fostered student independence.
Ms. Franklin	Differentiation; fostering student independence	Coach provided support on differentiation, provided access to activities and technology that supported differentiation and student independence.
Ms. Gonzalez	Fostering student independence; use of fact fluency sprints	Coach provided support and encouragement for promoting independence and use of the sprints. Coach split class so they could work with smaller groups.
Ms. Hanson	Pacing and differentiation	Helped break down the curriculum. Co-taught and modeled lessons to help with strategies and content.
Ms. Jones	Examining data to determine student needs; enrichment activities	Coach provided/modeled enrichment opportunities for students, helped teacher analyze student data. Coach observed teaching and gave feedback.
Ms. Kim	Pacing	Planning together. Observation and feedback on teaching. Some model teaching by the coach, allowing observation of methods and observation of students.
Mr. Larson	Analyzing student data for differentiation; effective use of intervention time	Coach taught participant how to analyze student data to plan for differentiation. Worked on effective use of intervention time. Coach was another adult for small group work.
Mr. Mitchell	Working with word problems	Coach provided strategies, resources, and materials. Coach observed a few lessons and provided feedback.
Ms. Quigley	Pacing	Coach helped plan lessons for pacing and provided resources and materials to help with lessons.
Ms. Riley	Student independence	Coach provided support and strategies for student independence Observed lessons, gave verbal praise.
Ms. Smith	Differentiation; modifying assessments	Coach assisted with setting up structures for differentiation and worked with a small group in class and for intervention time. Coach helped them to modify assessments and how to think about them going forward. Provided resources and materials.
Ms. Taylor	Pacing; using assessment data to help plan lessons for differentiation and intervention	Coach created calendar and structure for assessments Observed lessons and gave feedback.
Ms. Vasilli	Differentiation; pacing	Coach helped differentiate assignments. Provided positive feedback on teaching and pacing. Modeled questioning strategies and provided information about student thinking during independent work.

Ten of the 17 participants (59%) mentioned differentiation as a goal. While the teachers were trying to implement the new curriculum with fidelity, they were also trying to meet a wide variety of student needs. Differentiation took on different meanings, depending on the needs of the participants. Some were looking for strategies to modify assessments; some were looking for technology resources to aid with differentiation. Working on pacing was another frequently identified goal, named by six of the participants (35%). Participants were grappling with fitting expected lessons in the time frame allotted to mathematics in the school day. By working with the coaches, they hoped to develop strategies for addressing all relevant objectives and activities within the given time.

Four participants (24%) had a goal of fostering independence in their students. These teachers recognized that they struggled to have their students work independently on math activities and wanted to develop strategies for offering independence while minimizing unproductive student struggle.

Learning how to examine and use data to determine student performance levels and needs was a goal identified by three participants (18%). These teachers felt comfortable with differentiation, pacing, and the mathematical content of the curriculum but were not familiar with accessing and using data to help structure differentiation.

Other goals identified by just one participant were: understanding mathematical strategies, unit planning, incorporating fluency practice, structuring enrichment activities, effective use of intervention time, and working with word problems. This wide variety of goals seems to indicate that, while the coaches had some overall curricular goals, the coaching was personalized to the needs and wants of each participant.

The coaching activities described by the participants seemed well-aligned with the coaching goals. When differentiation was a goal, the coach provided materials, advice, or modeled strategies for differentiating the curriculum, instruction, or assessments. At times, the coaches acted as another classroom teacher, providing an extra person to do small group work when differentiating instruction. The coaches also modeled lessons or sections of lessons, giving the participants the opportunity to see a strategy in action and to see how their students engaged with those strategies. In several cases, the coach observed the teacher and offered feedback and validation.

Several participants noted that their coach provided assistance by creating or curating materials that were needed for implementing a new strategy or a component of the curriculum. This reduced or removed a barrier that the participants had perceived as preventing them from fully implementing the curriculum.

Support for Increased Self-Efficacy

Data from the teacher interviews support the increases in self-efficacy shown in the PMTE section of the MTEBI. Analyzing the tasks found in Table 2, it is seen that the coaches provided opportunities for the participants to experience all four of the components identified to develop and improve their teaching self-efficacy.

Physiological cues. As the teachers were working with a new curriculum, many expressed that, prior to the coaching cycle, they felt nervousness over using the representations expected in the curriculum, fitting in all of the components, and teaching the lessons with fidelity. Ms. Kim noted that her goal was “to fit everything in the whole lesson in one hour. Because the whole lesson, including the fluency and the debrief, all of that was taking over an hour.” Ms. Riley stated that “I know we're supposed to be teaching the program with fidelity, but the 60 [minutes required of the lessons] doesn't fit in the 45 [minute slot I have].” Ms. Hanson mentioned that she was not fully confident in teaching the new strategies used throughout the curriculum, and that becoming comfortable with the new strategies was like going through math class again and took her a lot of

effort. The coaches were able to address these issues with the participants so that they became more confident with their teaching. Several participants noted that the coaches encouraged them to try new strategies or components with the coach available as a backup, which made them feel supported and that they were sharing responsibility with the coach. As Ms. Gonzales noted, “Sometimes, when you're in one mode of teaching for so long, you don't really think outside the box [...]. So, it was nice to have that person say, ‘Let's try this’. I've actually gained more confidence.” Having the coach supervise and take responsibility for the outcome of trying a new strategy helped to reduce the nervousness felt by the teachers, which could have helped to improve their self-efficacy.

Verbal persuasion. Adding to the curriculum competencies they supported, the coaches also provided positive feedback on teachers’ lessons and interactions with students. Ms. Riley said that her coach gave her a lot of verbal praise, which was appreciated. Ms. Vasilli, who was concerned about her lesson pacing, noted that her coach timed a lesson and gave her very positive feedback on the pacing, which allowed her to feel more secure and to focus on other goals. By providing this positive feedback, the coaches alleviated teacher anxiety and promoted deeper engagement with the curriculum. This seems to have improved the participants’ confidence in engaging with students around mathematical concepts.

The persuasions offered by the coaches mentioned with physiological cues also can be thought of as verbal persuasion. Referring to trying math sprints in her class, Ms. Gonzales said, “I felt like it was too much pressure to do this. So [the coach] said, you know what, there's two of us here. Let's try it. and we did.” By expressing confidence that the teacher could successfully implement the strategy, the coach essentially loaned confidence to the participant and helped to bolster self-efficacy.

Vicarious experiences. The coaches worked with many of the teachers on their pacing of the curriculum and the inclusion of all required components. They also modeled lessons or portions of lessons, allowing the participants to observe the teaching of new strategies and pacing of a lesson. Ms. Hanson noted that the modeling of specific strategies by her coach, such as bar models and open number lines, has made her feel more confident in teaching those topics. Similarly, one of the coaches modeled some enrichment strategies for Ms. Franklin, who expressed that she now felt more comfortable with providing enrichment activities for her students.

Mastery experiences. As teachers incorporated more components of the curriculum, they felt that they were able to differentiate better for their students and address individual needs better. The coaches encouraged the participants to analyze student data and use the curricular resources to plan activities and individualized technology usage. Once she had success with the sprints, aided by the coach, Ms. Gonzales felt comfortable incorporating them on her own on a regular basis. Mr. Mitchell felt that his work with the coach on word problems was successful and “it's something that we can take into the future and hopefully tweak but use again, and again, and again.” In Mr. Larson’s class, “we decided to focus on the [software program] because that's tied directly to our [progress] testing, and I think it was really effective. You know, I'm seeing growth. Most of the students have gone up a level in their testing in that area.” By building in opportunities for mastery experiences, the coaching program helped the teachers gain confidence in their ability to work with the mathematics curriculum.

Outcomes expectancy. Some of the participants did note student improvement with the changes that were made during the coaching cycle, such as Mr. Larson noting the increase in progress test scores. What is surprising is that related items, such as “When the mathematics grades of students improve, it is often due to their teacher having found a more effective teaching approach,” did not increase significantly, and in fact decreased. The lack of increase in MTOE will be further discussed below.

Discussion

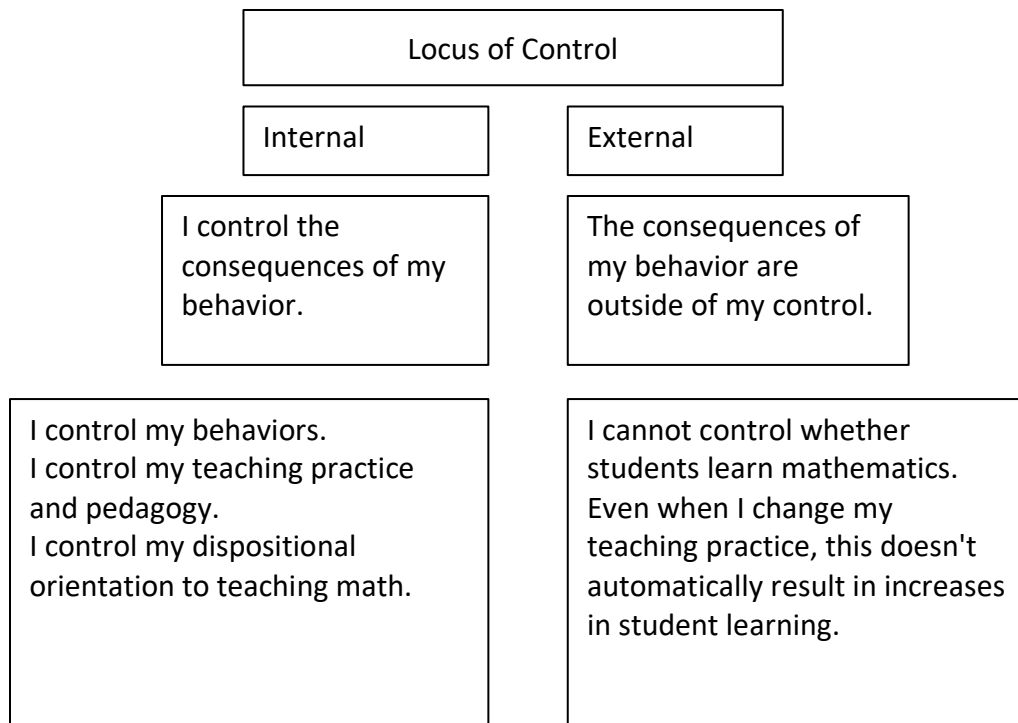
Personal Mathematics Teaching Efficacy (PMTE) increased significantly over the course of the coaching cycle. The components of the program - setting individualized goals, allowing for opportunities to practice new skills and strategies, observation by both the coach and participant, feedback, and reflection – were well-aligned with the progression suggested by White et al. (2015) and Hanft et al. (2004). Modeling, practicing, and feedback were found throughout the coaching process. These have been identified as the components most likely to lead to increased student achievement which is, ultimately, the goal of teacher professional development (Glover et al., 2023).

The types of support given to the participating teachers aligned well with the four factors that Bandura (1977) identified as contributing to self-efficacy, and also with the components of coaching Tschannen-Moran & McMaster (2009) theorized as building that self-efficacy. The coaches provided vicarious learning by teaching parts of lessons and leading small group learning with the classroom teacher observing them. When the coaches gave participants positive feedback, it allowed them to feel successful and assume mastery in their ability to enact the curriculum and teach effectively (Zuya et al., 2016). The coaches also provided encouragement to the participants to try new strategies and resources, which align with verbal persuasion. Also, through the feedback given to participants, the coaches were able to help alleviate some of the anxiety the teachers were feeling about enacting the curriculum with fidelity and fitting it within the time allotted for mathematics in the classroom.

Several participants noted that, due to the coaching, they had made material changes in their classroom instruction. These changes included differentiating instruction and assessment, changing the pacing of lessons, using data to inform their lesson planning, and incorporating new strategies or elements to their lessons. The coaching that leads to these changes in classroom practice has been linked to the increased teacher efficacy seen in the study (Kraft et al., 2018; Russell et al., 2020; Woolfolk Hoy & Spero, 2005).

The increase in Personal Mathematics Teaching Efficacy (PMTE) was heartening, but there was not a similar increase in Mathematics Teaching Outcomes Expectancy (MTOE). This indicates that, while teachers feel more confident in their mathematics teaching abilities, they do not feel more confident in their ability to impact students' understanding of mathematics. Affecting change in student outcomes is a tertiary effect of changing instructional strategies and methods, which indicates distance from what the teacher can control. Many aspects of student learning and achievement are removed from instructional interventions and hence may be perceived as outside of a teacher's control. An educator might be more confident that they can change their instructional strategies and methods but less confident that these will result in changes to student outcomes because changes to student outcomes rely upon other extraneous variables unrelated to what the teacher can control.

Returning to our operational theory using Rotter's Locus of Control (1966), instructional coaching interventions did improve teachers' internal locus of control for the consequences of their behaviors related to internal consequences to behavior changes. For instance, changed behaviors led to positive consequences in teachers' pedagogy, practice, and dispositional orientations to mathematics. However, additional changes – removed from the teachers themselves (i.e., student learning and student achievement) – remained in the external locus of control. This suggests coaching interventions can shift the locus of control toward an internal locus of control for consequences related to teaching pedagogy, practice, and dispositional orientation. Coaching interventions were less effective in shifting the locus of control from external to internal when focusing on student learning and achievement (see Figure 5).

Figure 5*Two Aspects of Locus of Control***Conclusion**

Mathematics coaching appears to be a strategy for improving teachers' Personal Mathematics Teaching Efficacy and supporting teachers as they work to enact curriculum. This coaching program allowed for individualized goals and strategies, which gave teachers voice and agency in the process. The coaches were able to incorporate the factors for self-efficacy improvement, such as mastery, vicarious learning, encouragement, and managing emotions (Bandura, 1977; Tschannen-Moran & McMaster, 2009), leading to greater teacher confidence.

That Mathematics Teaching Outcomes Expectancy did not change indicates that teachers are not convinced that their teaching has the greatest impact on student learning. Further research should be undertaken to explore why this facet of self-efficacy did not improve and what changes to the coaching process might be needed to help teachers increase their confidence in their ability to affect student achievement.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

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From Logistics to Cognition: A Review of *Digital Technology and Artificial Intelligence in Mathematics Education Assessment*

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Book Information

Title: *Digital Technology and Artificial Intelligence in Mathematics Education Assessment*
Editors: Eirini Geraniou, Cosette Crisan, and Manolis Mavrikis
Publisher: Routledge
Publication Date: 2026

Keywords: artificial intelligence in mathematics education, digital mathematics assessment, instrumental genesis, human-AI complementarity, digital equity

Introduction

As a secondary mathematics leader for a large urban school district in the United States, my work involves both policy and classroom reality. In our current climate, the discussion of digital learning is frequently reduced to logistical decisions, such as procuring hardware or selecting software. However, choosing digital tools for mathematics education carries far broader cognitive implications. As Pea (1985) observed, technology is not a neutral delivery mechanism; rather, "it becomes an indispensable instrument of mentality, and not merely a tool" (p. 175). Consequently, the dialogue surrounding digital integration must extend beyond administrative logistics to examine how these technologies fundamentally reshape instructional design and assessment. *Digital Technology and Artificial Intelligence in Mathematics Education Assessment* (2026), edited by Eirini Geraniou, Cosette Crisan, and Manolis Mavrikis, offers a vision for the future of digital learning in mathematics that extends far beyond this limited view. This compilation of international research, comprising 15 chapters by contributors from 11 countries, argues that moving from paper to screen is not merely a lateral shift; it fundamentally reshapes how students explore, manipulate, and communicate mathematical ideas.

Central Themes: Beyond Efficiency

Digital Technology and Artificial Intelligence in Mathematics Education Assessment (2026) is framed by several thought-provoking questions: How do we identify evidence of learning in the digital era? What does it mean to see the trail of learning a student leaves behind? A central theme throughout the 15 chapters is preserving mathematical inquiry in a context that prioritizes scoring efficiency. The authors warn that whereas digital tools expand opportunities for deep thinking, they also tempt educators and administrators to emphasize what is measurable over what is significant (p. 58).

The text identifies four pillars that resonate deeply with current school challenges:

1. The Nature of the Transition: Shifting to digital assessment changes the tools and techniques students choose to employ.
2. Conceptual Assessment: Platforms can now assess students' questions and thought processes, not just their final solutions.
3. Human-AI Complementarity: While Large Language Models (LLMs), such as OpenAI's ChatGPT, excel at communicating ideas, technical tools like Computer Algebra Systems (CAS) that enable software to manipulate and solve mathematical expressions symbolically remain necessary for mathematical precision.
4. Equity and Access: Digital tools can bridge the feedback gap in large classrooms but simultaneously risk widening the divide for those without consistent infrastructure.

Discussion of Interconnected Themes and Ideas

The transition from paper to digital platforms is far from a neutral act of digitizing worksheets. This shift affects more than just the format of a response by fundamentally altering the cognitive utilization schemes students employ to solve problems (Iannone et. al, 2026, Chapter 2; Winnberg, et. al., 2026, Chapter 3). This evolution creates a central tension between assessing students' understanding of mathematical concepts and their technical proficiency, raising a critical question for educators: to what extent does the tool itself define the significance of the task (Winnberg, et. al., 2026, Chapter 3; Vikberg, 2026, Chapter 4)? In Finland, for example, the move to digital high-stakes testing has highlighted that for assessment to be valid, technology must be deeply embedded in the curriculum and instruction well in advance of the exam (Vikberg, 2026, Chapter 4).

A theme developed over multiple chapters and various contexts is that when technology is successfully embedded, it moves beyond a simple interface and becomes a window into student cognition. Digital platforms offer a dashboard view of thinking, eliminating the traditional lag of manual marking and providing immediate, actionable data. Tools such as GeoGebra allow educators to monitor the live manipulation of geometric figures, revealing individualized needs in real-time (Ayoob & Olsher, 2026, Chapter 5), whereas sophisticated multiple-choice designs can pinpoint misconceptions and reduce cognitive load for multilingual learners (Barzel et. al., 2026, Chapter 9). This efficiency is particularly transformative in large-scale university settings, where digital systems allow instructors to facilitate open-ended, example-eliciting tasks that would be logistically impossible to mark manually (Fahlgren & Brunström, 2026, Chapter 10).

However, the visibility of student data is only as useful as the feedback it triggers. Black & Wiliam (1998) emphasize that, "feedback to any pupil should be about the particular qualities of his or her work, with advice on what he or she can do to improve, and should avoid comparisons with other pupils." (p. 143). Effective digital feedback must therefore strike a delicate balance: it must support the student without giving away the solution. Research from the Netherlands recommends a tiered approach that incorporates error-specific hints followed by worked solutions to foster self-guidance (van der Hoek et al., 2026, Chapter 11). Furthermore, Interactive Learning Environments can now detect whether a student is engaging deeply or merely taking a surface approach (Margeti & Mavrikis, 2026, Chapter 13). While the emergence of atomic feedback (reusable, bite-sized units of commentary) allows for more elaborate responses, the human element remains vital; teachers must remain central to the feedback process to ensure guidance is tailored and nuanced (Moons, 2026, Chapter 14).

The frontier of this partnership between technology and teachers lies in machine learning and artificial intelligence (AI), which offer personalized tutoring but introduce new challenges regarding noise and randomness. Whereas AI has made strides in the automated scoring of open-ended

questions through semantic representation, it still struggles with complex mathematical syntax and student-generated imagery (Baral et al., 2026, Chapter 7). This technological uncertainty requires a reconceptualization of the student's role; they must be intentionally taught to handle the hallucinations of AI to avoid unproductive conversational loops that lead to dead ends rather than legitimate problem-solving guidance (Cusi & Contel, 2026, Chapter 8) and to approach dialogue with AI thoughtfully rather than uncritically accepting outputs (Thomsen et al., 2026, Chapter 15).

Ultimately, the goal is to ensure mathematics education does not devolve into mere button pushing. Pinkernell and Weigand (2026, Chapter 6) emphasize the importance of assessing conceptual knowledge through basic mental models that represent core mathematical understanding. Building on this, Thomsen, Misfeldt, & Jankvist, (2026, Chapter 15) discuss how CAS and LLMs support student tasks through three distinct types of mediation: pragmatic, which involves the use of AI as a problem-solving tool; epistemic, in which AI helps a student understand a concept; and justificational, wherein the output of the tool serves as the main justification of a mathematical claim. As students learn to navigate these technologies, educators must encourage critical questioning of AI-generated responses rather than allowing outputs to become "techno-authoritarian proof schemes" accepted without scrutiny.

Reflective Analysis for Mathematics Leaders

In a traditional setting, summative assessment has largely been post-mortem, a term coined by Douglas Reeves (2005). Whereas traditional assessment reveals what the student did not know after the instruction was already concluded, this text calls upon educators to re-evaluate the purpose of assessment. Digital platforms shift the purpose from summative evaluation to live navigation. Modern digital dashboards promise to empower educators with timely, customized feedback. Moons (2026, Chapter 14) describes how AI-teacher partnerships can generate feedback based on structural errors in math classrooms. As these tools improve, digital assessment will increasingly be used to adjust instruction live rather than retrospectively. For teacher educators, this requires a shift in how we prepare pre-service teachers to "read" a classroom, as using mathematical software demands balancing real-time observational attentiveness with digital dashboard fluency.

The text also challenges educators to consider what counts as mathematical skill. Digital assessments now measure both mathematics concepts and technological literacy, such as AI prompting or CAS manipulation. This presents a curricular dilemma: if a CAS-enabled calculator is allowed on all items, we may unintentionally stop assessing manual algebraic manipulation. As described by Stacey (2024) mathematical "invisibility" presents a very real challenge, as calculations are increasingly "outsourced" to machines" (p. 226). We must therefore intentionally decide which skills, both mathematical and technological, we value most. The book challenges us to consider whether prompt engineering is becoming a subset of mathematical communication. If so, our assessment frameworks must evolve to give credit for the logic of the query, not just the accuracy of the result.

A key emphasis of the text is its timely discussion of *Instrumental Genesis*, the idea that our tools fundamentally change our mental schemas. Digital task design dictates how students conceptualize ideas. We must shift our focus from easy-to-automate tasks to conceptual tasks that require deeper understanding. This requires curriculum designers and mathematics leaders to shift their own thinking from marking the answer to evaluating the relationship between the student and the digital environment. This is a profound shift in teacher professional development, moving from how to use the tool to how the tool uses the student's mind.

The persistent challenge of equity presents another critical question for educators. Gottschalk and Weise (2023) define digital equity as the state in which “all individuals have the digital capacity (including access and skills) to fully participate in society” (p. 8), emphasizing that, “The rapid shift to digital learning was more difficult for particular student groups, especially those from vulnerable or disadvantaged backgrounds, and for those who lacked the requisite access and infrastructure” (p. 11). Chapter 12 (Sangwin & Oyengo, 2026) highlights the ability to provide feedback to hundreds of students simultaneously, potentially improving equity in resource-strapped environments. However, this assumes access to digital infrastructure and high-speed connectivity. For a leader in a large urban district, the most pressing takeaway is that expanding digital instruction risks widening the gap between those with stable access and those without. Digital equity is not just about having a laptop; it is about having the digital capital to navigate complex AI interfaces without becoming frustrated or lost in unproductive loops.

Limitations

As a compilation of international research grounded in varied institutional contexts, the text presents a natural trade-off: practitioners will find certain chapters immediately actionable, while others feel distant from everyday school realities. Furthermore, the volume’s academic density may prove daunting to time-pressed leaders seeking a straightforward entry point into AI’s influence on local mathematics instruction. Practitioners and administrators will likely gain the most value by using the introductory chapter summaries to curate a targeted reading path tailored to their district’s specific needs. Finally, while the text offers exceptional theoretical depth regarding the mechanics and implications of digital assessment, its concrete roadmap for under-resourced K–12 leaders remains limited, leaving open critical questions about how to operationalize this vision within large, complex public school systems.

Conclusion

Although the text is academically rigorous and filled with technical terminology such as ILEs (Interactive Learning Environments), its heart is the daily life of teachers and students. It acknowledges that digital assessment creates a new form of work involving technical orchestration and question authoring. We cannot expect teachers to navigate this without dedicated, sustained professional development.

This book is indispensable for educators, researchers, and leaders at the intersection of mathematics and technology. It provides empirical evidence and theoretical grounding to ensure that, as we move into an automated future, we do not lose the human trail of learning that makes mathematics vital. It is a call to action for the mathematics education community to take the lead in defining AI’s role in the classroom, rather than letting the technology companies define it for us.

The authors received no financial support for the research, authorship, and/or publication of this manuscript

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