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A Review of Analytic Frameworks for Noticing in Mathematics and Science: Comparing Noticing Frameworks Across Disciplines and over Time

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Abstract
We review analytic frameworks related to the study of noticing in mathematics and science education for the purpose of suggesting trends in research literature across both disciplines over time. We focus on highly cited articles in both mathematics and science noticing research, along with recent articles in both disciplines. We focus specifically on research articles that include an analytic framework, to understand the state of how data on noticing are analyzed. We conducted an extensive review of literature, intentionally related to population, temporality, methodology, and quality. The purpose was to provide an overview of the field of noticing, based on particular search criteria for articles including an analytic framework. To be considered an analytic framework, the article had to include a framework that could be used to analyze teacher noticing. We found frameworks in science education are frequently adapted from mathematics education and are moving toward pairing noticing with aspects of effective instruction (formative assessment, sense-making, pedagogical content knowledge), whereas the frameworks in mathematics education now consider context and equity, which was not an explicit focus in the initial noticing literature.

Keywords Assessment · Equity · Framework · Noticing · Professional vision

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Introduction

Research on teacher noticing has expanded rapidly in recent years, with roots tracing back more than two decades (Gibson, 1986; Goodwin, 1994; Mason, 2002; Schack et al., 2017; Sherin et al., 2011). As work on noticing has evolved and been conducted in various contexts, researchers have used different definitions for noticing, including *attending* (e.g. van Es & Sherin, 2002) versus *decision-making* (e.g. Jacobs et al., 2010), *teacher noticing* (e.g. Mason, 2002) versus *professional noticing* (e.g. Jacobs et al., 2010), among others. Researchers have also used different terms and phrases to refer to the same concepts (Weston & Amador, 2023), further complicating understanding about noticing, which potentially interferes with optimally supporting teacher development. Jacobs and Spangler (2017) indicated concern about the lack of a coherent use of the term "noticing" and suggested that if future researchers are not clear, the term could eventually be *all encompassing* and thus lack meaning. Researchers also evaluate noticing in many different ways. In a recent study, Weyers et al. (2023) conducted a scoping review of standardized instruments in noticing and found that assessment quality varies considerably, and validation measures are rarely conducted. These researchers noted that other than mathematics, few instruments are subject specific. As a result, understanding research on noticing—including making sense of findings for the purposes of teacher support—is difficult and confounded when considering multiple disciplines, such as mathematics and science.

To advance the understanding of noticing, clarity is needed about variations in the ways researchers collect and analyze data on noticing. Additionally, more needs to be known about noticing in disciplines beyond mathematics (the primary content area of noticing research). We purposely focus on noticing in mathematics and science, as there are variations in both how researchers conceptualize noticing (Weston & Amador, 2023) and how they analyze noticing (Amador et al., 2021). Furthermore, the disciplines of mathematics and science are chosen as focal areas of study because of similarities in theoretical underpinnings that have undergirded the disciplines (i.e. constructivism, Cobb, 1994), the frequent integration of the two content areas (Furner & Kumar, 2007), and commonalities in research design (Kelly & Lesh, 2012). Our former work (Amador et al., 2022; Weston & Amador, 2023) focused on diverging conceptualizations of noticing in mathematics and science, therefore raising questions about the analytic processes and frameworks used in the past and present in both content areas. We consider a focus on both disciplines important, as teacher noticing has become a core construct for teacher education (Schack et al., 2017).

Most of the research articles published on noticing have been confined to one discipline, meaning they focused exclusively on mathematics or science. Some researchers have bridged the disciplines with a focus on noticing in both content areas (e.g. Jazby et al., 2022); however, there is still a need to explore how research on noticing in both disciplines has evolved. As a result, we consider highly cited publications that have been used by other researchers and contemporary work that allows us to describe some current aspects of the field. Our synthesis methodology included reading numerous publications about mathematics and science noticing and then selecting and analyzing 12 studies in mathematics and science teacher noticing from 2002 to 2022. We focused on the most cited works over the past twenty years as well as recent works from the past two years (with half of the selections coming from each category and discipline). We focused on empirical publications that included an analytic framework for teacher noticing to answer the following questions:

1. What are the characteristics of analytic frameworks in mathematics for noticing that have been (a) recently published and (b) highly cited, and how do they compare over time?
2. What are the characteristics of analytic frameworks in science for noticing that have been (a) recently published and (b) highly cited, and how do they compare over time?

Framing Literature

Given that the purpose of this article is to present a description of research on noticing, we frame this paper based on the roots of noticing to consider the evolution of the field. Mason (2011) defined *noticing* as an everyday, frequent human action. In an educational context, Mason differentiates that noticing is a "collection of practices designed to sensitize oneself so as to notice opportunities in the future in which to act freshly rather than automatically out of habit" (p. 35). The notion of acting "freshly" instead of "automatically" signifies the heightened awareness (Mason, 2002) necessary for teacher noticing. The purpose of noticing is that the resulting action is purposeful and not habitual.

At a similar time to Mason and Spence (1999), Goodwin (1994) focused on professional vision and the notion that members of a professional practice, such as teaching, use discursive practices to shape events, resulting in a practice-based theory of knowledge and action. Essentially, professional vision encompasses "socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (p. 606). Although Goodwin did not focus specifically on teaching as a profession, the idea of professional vision has permeated education contexts. For example, Sherin and Han (2004) indicated that the ability teachers have, to see and interpret critical aspects of a classroom, is their professional vision. With professional vision, Sherin and Han (2004) argued that teachers learn to attend to particular events in a classroom and reason about events. The focus on paying attention and then reasoning about an event aligns with Mason's (2002, 2011) ideas about noticing to recognize occurrences and act freshly as opposed to habitually.

Over the years, these foundational constructs of teacher noticing and professional vision influenced many conceptualizations of teacher noticing (Kaiser & Yang, 2023; Weston & Amador, 2023). As conceptualizations of noticing formed, researchers focused on how individual teachers learn to notice and created frameworks to measure noticing to show development (e.g. van Es, 2011), or to assess noticing (e.g. Star & Strickland, 2008).We were interested in the evolution of how researchers analyze teacher noticing, meaning, for example, what is different about the frameworks used to analyze noticing? What contribution do these frameworks make to the field? And, if the ultimate goal is to support teachers to act freshly rather than habitually (Mason, 2002, 2011), what role do frameworks play in supporting the mathematics and science education fields to understand the extent to which this type of noticing is happening in teaching contexts? The following describes our systematic process to select and analyze relevant articles for these considerations.

Method

We conducted a systematic search to select publications for review to describe the noticing frameworks used in mathematics and science education research literature. We made the decision to include literature with a high number of citations and that seemed central or pivotal to the particular content area, as well as recent literature published in 2021 or 2022. Based on Cooper et al. (2019), our approach to *coverage* can be described as *central or pivotal* because we "concentrate(d) on works that were highly original when they appeared" and, in the case of the historical pieces we selected, "influenced the development of future efforts in the topic area" (p. 6). To provide an in-depth review of the frameworks used for analyzing noticing, we include 12 publications, with half focused on mathematics and half on science, with equal division between those highly cited (published 2002–2020) versus recent ones (published 2021–2022). Given the purpose to describe frameworks for analyzing noticing, our coverage approach was a conscious choice to disrupt the tendency to condense more ideas; instead, we focused on providing readers with substance about fewer articles. We acknowledge metasyntheses of an extraordinary amount of literature are significant contributions; however, the aim of this project was different. We were instead interested in tracing an intentionally focused literature collection so that we could preserve and convey more of each research group's language and ideas and provide an in-depth description of a few articles rather than a cursory report on many. Reducing a detailed description of frameworks to include a greater number of articles would remove the ability to explain a diversity of ideas, which was the aim of the project. We recognize that other researchers may have selected different publications for a similar analysis. Our decision process is further described below.

Search Criteria, Selection Process, and Analysis

We set our search criteria parameters on topic, population, time, and methodology (Thunder & Berry, 2016) as well as quality. The *topic* of the targeted literature was mathematics or science teacher noticing. Keyword searches included each of the following: AND math* or AND science: noticing, teacher noticing, professional noticing, professional vision, attend*, attention, interpret*, sense making, professional vision, responsive teaching, reflective teaching, pivotal moment, contingent moment. To be considered a publication with a framework, the piece had to use language about how noticing was operationalized and explicitly describe its analytic framework for noticing. Given that this is part of a larger project that also investigates teacher noticing conceptualizations (Weston & Amador, 2023), we had to determine whether publications were better considered a *conceptualization* or a *framework* piece, as some publications included both. A conceptualization meant a description of noticing, whereas a framework meant a clear analytic tool or process that could be used to analyze data.

To set our *population* parameter, we focused on prospective or practicing teachers in primary or secondary school to focus on mathematics and science teaching prior to the post-secondary level. To consider *temporality* as a parameter, we limited the search to literature published between 2002 and 2022 because of foundational works published in 2002 (Mason, 2002; van Es & Sherin, 2002) that influenced teacher practice and noticing research (Cooper et al., 2019). *Methodological* criteria included qualitative, quantitative, or mixed methods research, namely articles or book chapters, and did not include dissertations, reports, white papers, or published conference proceedings; works that presented frameworks that could be used for empirical research, but did not include the actual empirical study were also considered. For *quality* criteria, there had to be a clear framework used and described and the description of analysis had to be clear enough that it seemed possible to replicate with few ambiguities.

Education and social science search engines were used within each discipline (mathematics and science)—including ERIC, Education Research Complete, Teacher Reference Center, Social Sciences Citation Index, and Sociological Abstracts. We conducted controlled vocabulary searches, keyword searches, abstract searches, and citation searches. To select the publications for inclusion, the two authors searched mathematics and science education journals and books. The first goal was to select the six highly cited publications (three in mathematics and three in science). Both authors conducted searches for the two categories using the aforementioned keywords and search engines, and compiled records of publications that had a high number of citations. Searches were discontinued when multiple search engines returned the same publications. The two authors then compared their lists, conducted additional searches together, and agreed on the six highly cited publications.

The second goal was to select six recent works, which was challenging given the short timeframe for recent publications to be cited. Both researchers independently conducted searches with 2021–2022 date parameters and considered the journal quality in mathematics (Williams & Leatham, 2017) and in science (Scimago Lab, 2022). Focusing on notable publication venues, each researcher selected six publications for each of the two recent categories (mathematics and science) that included themes that were common to other papers and seemed representative of the central ideas being published about in the literature (e.g. equity), without selecting pieces by the same author. The authors then refined the selections together, resulting in a consensus on the included publications. Our selection process did not result in a singular possible list of publications about noticing frameworks, nor are findings representative of all works on noticing; however, the transparency of our process and analysis of the resulting publications provides a contribution to the field of noticing and takes steps toward understanding and integrating ideas across disciplines. A table in the supplementary material provides an overview of the focal articles.

To analyze the articles, we first read each article without initial analysis to understand the content (although, due to the exhaustive search process, most articles had already been read during the selection phase). One author then reread each article with particular attention to the analytic framework presented in the article and wrote memos in accordance with constant comparative methods (Corbin & Strauss, 2008). We repeated the reading and memo process for all three publications in the given subset and all four subsets. The author who did not write the memos reviewed the memos of the other author for accuracy and clarity and fact-checked claims made. After writing the memos and the alternate author reviewing the memos, the authors collectively analyzed the memos for themes across each of the four subsets of the articles. Once the extended memos were written and reviewed by the alternate author, the authors each analyzed their memos for themes across the subsets of pieces. Themes were determined, and the authors catalogued evidence in each article that related to particular themes. The authors then worked collaboratively to determine results, based on the memos and theme analysis. The following section describes the findings from this review.

Results

Highly Cited Articles on Noticing in Mathematics (2002–2020)

Sherin and van Es (2009) Sherin and van Es (2009) provided two analytic frameworks for analyzing professional vision, which they describe as a "particular way to notice" (p. 22). Of the two frameworks provided, the first, entitled *Investigating Professional Vision in the Video Club Meetings*, focuses on analysis of professional vision in the context of video clubs. Sherin and van Es claimed there are two components to professional vision: Selective Attention and Knowledge-Based Reasoning. Within Selective Attention, they claimed teachers focus on an Actor, which they defined as Student, Teacher, or Other. They also include Topic, which encompasses Management, Climate, Pedagogy, and Math Thinking—all aspects related to who is noticed and the topic of noticing. Within Knowledge-Based Reasoning, the focus is on the stance taken when noticing aspects of the video club, and codes include Describe, Evaluate, and Interpret. Finally, data were analyzed for the Strategy used to explore student mathematical thinking, which included the codes Restate Student Ideas, Investigate Meaning of Student Idea, and Generalize and Synthesize Across Student Ideas.

In contrast to this framework for analyzing Video Club Meetings, Sherin and van Es (2009) published a second framework, which was used to characterize teacher actions related to professional vision during a lesson. The framework for analyzing classroom observations is used to analyze classroom contexts when students raise a mathematical idea. This framework includes the two same components as the first framework: Selective Attention and Knowledge-Based Reasoning. Categories for Selective Attention include Disconfirming Evidence (the teacher does not consider a student idea as an object of inquiry) and Confirms Evidence (the teacher considers student idea as an object of inquiry). Categories for Knowledge-Based Reasoning include Disconfirming Evidence (the teacher does not engage in reasoning about student ideas), Confirming Evidence (the teacher reasons about student ideas), and Strategy Used to Explore Student Math Thinking (the teacher investigates the meaning of student ideas or generalizes and synthesizes across student ideas). The contributions of this work in 2009 included two specific frameworks that could be used to analyze noticing in two different contexts: video clubs in which teachers talk with each other and classroom observations. The frameworks gave mathematics education researchers a way to talk about the various dimensions of noticing and what could be noticed and how it could be noticed. Of the two frameworks, the first focused on analyzing video club interactions includes elements that continue to be commonly used for analyzing data on noticing in video club meetings and in other contexts where teachers write or verbalize their reactions to classroom events (e.g. Wallin & Amador, 2019).

Jacobs et al. (2010) Jacobs et al. (2010) developed a framework for analyzing *Professional Noticing of Children's Mathematical Thinking*, which focused on teachers' ability to Attend, Interpret, and Decide how to respond based on written responses to three prompts. The analytic focus was assigning scales for the extent to which teachers provided evidence of their engagement with children's mathematical thinking. The first scale was written to analyze data from a prompt to assess participants' expertise in attending to three strategies. For the analytic process for the first scale, Jacobs et al. (2010) disaggregated teachers' mathematically significant details and determined whether or not the teacher's response focused on those details. The analysis then focused on whether the participant provided evidence for the children's strategies that they had attended to, coded as Evidence or Lack of Evidence. The emphasis for coding the attending dimension centered on the presence or lack of evidence to support claims. The second scale was written to analyze data from a prompt to assess participants' expertise in interpreting children's understandings. The focus was on the degree of evidence provided to demonstrate an interpretation of children's mathematical thinking. Codes included Robust Evidence, Limited Evidence, and Lack of Evidence. The third scale was written to analyze participants' expertise in deciding how to respond based on children's understanding. Participants were prompted to include problems and rationale in their responses, which were then coded based on the extent of the evidence provided for how a participant would decide to respond. Codes included Robust Evidence, Limited Evidence, and Lack of Evidence. One contribution of this work was the delineation of noticing as based on the three component skills—attending, interpreting, and deciding to respond. Building from this work, hundreds of other papers have included mention of these three components, and many have structured coding schemes around the three components and coded specifically based on the inclusion of evidence or lack thereof, similar to the coding structure Jacobs and colleagues present (e.g. Dindyal et al., 2021).

Van Es (2011) Van Es (2011) published the *Learning to Notice Framework*, which includes elements similar to those of Sherin and van Es (2009). The intent of the framework was to provide an analytic tool to characterize and analyze the process of learning to notice student mathematical thinking. The framework, which stemmed from analysis of video club data, focuses on What Teachers Notice and How Teachers Notice, with four levels for each category: Level 1 *Baseline*, Level 2 *Mixed*, Level 3 *Focused*, and Level 4 *Extended*. Descriptors are provided for each level. For What Teachers Notice, the Level 1 code states, "Attend to whole class environment, behavior, and learning, and to teacher pedagogy," whereas the Level 4 code states, "Attend to the relationship between particular students' mathematical thinking and between teaching strategies and student mathematical thinking" (p. 139). The focus shifts from a more general focus on noticing, to a specific focus on students' mathematical thinking with the more advanced levels. For How Teachers Notice, the Level 1 code states, "Form general impression of what occurred; provide descriptive and evaluative comments; provide little or no evidence to support analysis," whereas the Level 4 codes states, "Highlight noteworthy events; Provide interpretative comments; Refer to specific events and interactions as evidence, Elaborate on events and interactions; Make connection between events and principles of teaching and learning; On the basis of interpretation, propose alternative pedagogical solutions" (p. 139). This progression along the levels of How Teachers Notice becomes increasingly interpretive, connective, and elaborate. A contribution of this work was a way to analyze noticing across a progression, from more rudimentary noticing to more advanced noticing. The framework for learning to notice student mathematical thinking provides language that can be used to describe variation in noticing, both focused on what was noticed and how the noticing was conveyed. Numerous researchers (see Amador et al., 2021) have used the framework to analyze their own data sets, relying on the levels of noticing van Es (2011) presents as descriptors.

Recent Articles on Noticing in Mathematics (2021–2022)

Louie, Adiredja and Jessup (2021) Louie et al. (2021) recently developed and published a sociopolitical framework for conceptualizing mathematics teacher noticing. The *Framing, Attending, Interpreting, Responding (FAIR) Framework* is designed to support others to recognize deficit noticing. Louie et al. (2021) argued that prior norms have framed "mathematics learning as absorption of a universal, objective, and fixed body of knowledge, students primarily as mathematical receivers, and interactions between students as relatively inconsequential for learning" (p. 98). In the anti-deficit framework provided, three frames were presented, with a focus on students, mathematics, and interactions: "Framing students as full human beings with many resources; Framing mathematics learning as a creative exploration of ideas; Framing interactions and interpersonal relationships as integral to learning" (p. 102). Within each of these frames, descriptors were provided for attending, interpreting, and responding, which are aspects of noticing that build on the work of Jacobs et al. (2010). Within the framing aspect focused on students, attending means recognizing students as unique individuals with their own personalities, interpreting draws on students' ways of being as resources, and responding includes giving students space to be themselves and leverage their ways of being to support their own learning and the learning of their peers. Within the framing aspect of mathematics, attending means recognizing the diverse ways of working and making sense of mathematics, interpreting focuses on students' work as sensible and valuable, and responding includes giving students space to develop their own ideas and approaches and leveraging them to advance mathematics learning. When framing interactions, attention is focused on the nature of students' bonds with peers, interpreting is indicated by strong egalitarian bonds as learning resources, and responding includes giving students space to build relationships with each other and to leverage those relationships for learning. Although we perceive the framework described as a conceptual framework, with less emphasis on the analytic properties, the ideas presented are those that could be used for analysis and consideration of how noticing occurs. A contribution of this work is the anti-deficit frames that emphasize meaningful mathematics learning through relations of equality, collaboration, and dependence. Louie et al. (2021) noted that their framing disrupts "hierarchies among students, acknowledging differences but positioning every student as an equal contributor," which highlights students' connections and equal status (p. 104). Researchers could adopt the FAIR framework as grounding for analytic analysis from a cultural perspective that could be applied to noticing experiences.

Stockero (2021) Stockero (2021) recently analyzed prospective mathematics teachers' noticing using two methods. The first was originally introduced by Leatham et al. (2015) and is called the *Mathematically Significant Pedagogical Opportunities to Build on Student Thinking* (MOSTs), which occur at the intersection of student mathematical thinking, significant mathematics, and pedagogical opportunity. The second coding framework Stockero (2021) introduces, *Coding Framework for Attributes of Noticing*, draws on Stockero (2008) and van Es and Sherin (2008) and centers on attributes of prospective mathematics teachers' noticing. The intent was to develop categories for alignment between prospective mathematics teachers' noticing during instruction and the goal of a noticing intervention to support attending and interpretation of high-leverage instances of students' mathematical thinking. Three focal coding attributes were identified: Agent, Specificity of Mathematics, and Focus. For Agent, the focus was on who or what was the object of noticing and codes included Teacher, Teacher/Student (teacher as primary focus), Student/Teacher (student as primary focus), Student Group, Individual Student, and Math. For Specificity of Mathematics, the focus was on whether and how the mathematics in an instance is discussed. Codes included Non-Math, General Math, and Specific Math. For Focus, the descriptor read, "For instances with students included in the agent, what about the student(s) was attended to" (p. 79). Codes included Affective Issue, General Understanding, Mathematical Interaction, Noticing Student Mathematical Thinking, and Analysis of Student Mathematical Thinking. A contribution of this coding protocol—the use of the MOST framework alongside the attribute framework—is that Stockero (2021) was able to analyze whether noticing skills developed during an intervention were able to transfer to support prospective mathematics teachers' noticing while teaching during student teaching. The attribute framework provides a mechanism to talk about the focus of noticing and the relation to mathematics and provides descriptors to illuminate what prospective teachers attended to related to the student.

Van Es and Sherin (2021) Van Es and Sherin (2021) published the *Revised Learning to Notice Framework*, an extension of their earlier work (van es & Sherin, 2002). The 2002 framework included Attending ("identifying noteworthy features of classroom interaction") and Interpreting (using "one's knowledge and experiences to make sense of what is observed") and "Make connection between what is noticed and broader principles of teaching and learning" (van Es & Sherin, 2021, p. 19). In the revised framework, the idea of attending is modified to include selecting and *disregarding* particular features of instruction that are less consequential. The idea of interpreting is reconsidered to include a stance of inquiry about what is observed, recognizing that, "interpreting is not only about trying to make sense of a phenomena but also involves seeing observed phenomena as something worth trying to figure out" (van Es & Sherin, 2021, p. 22). The third and final dimension, shaping, is the process of creating interactions while teaching that provides opportunities to attend to and interpret students' noteworthy mathematical thinking and interactions. A contribution of this revised framework is that it was purposefully constructed to modify an existing long-standing framework for noticing (van Es & Sherin, 2002), based on two decades of extant literature and continued analysis, resulting in a well-articulated framework with refined descriptions. Additionally, the revised framework was applied to the same data set as the original, illuminating the affordances of the framework for analyzing noticing. Finally, the inclusion of the shaping component of the framework provides the mathematics education field with a way to consider the opportunities that teachers can create through shaping, to actively give rise to opportunities to notice within one's environment.

Considering Analytic Noticing Frameworks for Mathematics: Then and Now

The three aforementioned highly cited works in noticing research (Jacobs et al., 2010; Sherin & van Es, 2009; van Es, 2011) include two of the most well-followed and established cognitive frameworks used in mathematics education research in the past two decades (Amador et al., 2021). The work of van Es (2011) builds on the work of Sherin and van Es (2009) and further articulates aspects of noticing that can be analyzed. In those works, the focus is on the actor, topic, and stance, with consideration of who and what is noticed. The work of Jacobs et al. (2010) assumes a different perspective, with the definition of noticing as the skills of attending, interpreting, and deciding to respond. These frameworks both include aspects related to the level of interpretation provided when noticing occurs and the extent to which evidence is provided to support the claims. All three articles presented in the recent work section build from the prior work of Jacobs and colleagues or van Es and Sherin but do so in ways to illuminate the divergence in how noticing is analyzed in the field of mathematics education.

Louie et al. (2021) include a consideration of equity, whereas Stockero (2021) focuses on attributes of prospective mathematics teacher noticing with a specific focus on high-leverage instances of students' mathematical thinking. In yet another direction, van Es and Sherin (2021) revised their framework to include *shaping* as a third dimension, which highlights the context of noticing and considers the process of creating interactions during teaching that make way for attending and interpreting instances of student thinking. These three new frameworks all contain some *consideration of the contextual aspects related to noticing*. Louie focused on the equitable aspects of noticing and the context of students' lives and lived experiences, whereas Stockero considers the contextual opportunity of high-leverage instances of students' mathematical thinking and the prevalence of those opportunities for noticing to take place. Similarly, van Es and Sherin suggest that the teacher shapes the opportunities for noticing that may exist, and the context of the classroom and student experiences is at play when noticing occurs. We further highlight a second major theme in these recent works, that *all three new frameworks are based on the original ideas of Jacobs and colleagues and van Es and Sherin.* These center on the idea of attending to and interpreting students' mathematical thinking. We acknowledge that these are the conclusions drawn from the six papers on mathematics and may not be representative of all papers on noticing in mathematics. Next, we will highlight articles from science education, following a similar organizational structure.

Highly Cited Articles on Noticing in Science (2002–2020)

Russ and Luna (2013) Russ and Luna (2013) worked to formalize the link between teachers' epistemological framing and their attention. They argued that local patterns in teacher noticing provide the opportunity for inferring teacher cognition and epistemological framing. The authors note that prior efforts have been made in science education, to *document* teacher attention (Hammer & van Zee, 2006; Larkin, 2012; Maskiewicz & Winters, 2012; Roth et al., 2011) but at the point of their writing, science education researchers had not yet established analytic tools for *examining* attention. Russ and Luna note that within their science education context, they turn to analytic methods of mathematics education researchers to study teacher noticing—this is in part why the citation numbers for science noticing articles are lower than for mathematics noticing articles, because a majority of the science education articles cite mathematics education frameworks. They contend that local patterns in teacher noticing allow for inference that leads to epistemological framing. The analysis includes three phases, with the coding framework for noticing being the focus of Phase 1. Phase 1, the presented framework for noticing, includes three coding schemes: (a) participant structure, with codes of Teacher-Led Large Group Discussion, Student-Led Large Group Discussion, Lab Work, and Transition; (b) particular type of talk, with the codes Question and Answer, Explanation, Question, Classroom Logistics, and Casual Talk; and (c) student thinking, with the codes Student Thinking, Student Engagement, Student Characteristics, Discourse, and Task Management. Phase 2 data analysis focuses on identifying patterns in codes based on clips and reflections, given the aforementioned categories, and in Phase 3, inferences about framing were made. The researchers worked to use patterns identified in noticing (from Phase 1) to draw conclusions about a teacher's epistemological framing. Russ and Luna claim there is a two-way relationship between a teacher's epistemological framing and patterns in teacher noticing, a contribution possible because of the use of analytic focus of noticing. Another contribution of their work is the creation of an analytic science education framework that focuses on local patterns in teacher noticing. In the present case, the framework was used to analyze data from one secondary biology teacher, but the authors claim that the framework is applicable beyond their initial context.

Barnhart and van Es (2015) Barnhart and van Es (2015) studied science teacher candidates' analysis of videos of their own teaching. Teacher candidates were specifically asked about the instruction they provided in the clips, the strategies they used to monitor student learning, and their own learning that resulted from the video clip experience. Although the analysis was multi-staged, the following focuses on the analysis of noticing and the accompanying framework. The first phase of analysis was based on prior research on teacher noticing and reflection (Davis, 2006; Hiebert et al., 2007; Levin et al., 2009; Mason, 1998; Santagata, 2011; van Es, 2011; van Es & Sherin, 2002), with a focus on attending, how instruction was analyzed, and responsive decisions. The authors created a framework for the Levels of Sophistication for Noticing Skills. The framework includes three skills: attending, analyzing, and responding. For each of these skills, descriptors are provided for three levels of sophistication: Low Sophistication, Medium Sophistication, and High Sophistication. For Attending, Low Sophistication includes aspects such as "Highlights classroom events" and High Sophistication includes "Highlights student thinking with respect to the collection, analysis, and interpretation of data …" (p. 87). For Analyzing and Responding, low and high descriptors are included. Barnhart and van Es assigned numbers to the sophistication categories and compared the attending, analyzing, and responding of secondary science teacher candidates, demonstrating the framework's applicability for data analysis from a science education context. Another contribution, according to the authors, is that the framework provided a way to understand the noticing capabilities of science teacher candidates, so the teacher educators could work to support the development of noticing. Analyzing data with the Level of Sophistication for Noticing Skills allows researchers to track the development of noticing over time.

Luna and Sherin (2017) Luna and Sherin (2017) implemented video clubs to support science teachers' noticing. A two-level coding scheme, based on van Es and Sherin (2008), was created to analyze the discussion topic focus, aspects of a student's science ideas being discussed, and how the student's science ideas were discussed. In the first level of coding, the authors segmented the transcripts and four codes emerged: Student Characteristics (when talk was on a student attribute or group of students), Classroom Climate (when talk was on the social environment), Pedagogy (when talk was on aspects of teaching), and Student Science Idea (when talk "centered on students' thinking and reasoning about the science at hand" (p. 288)). In the second level of coding, Luna and Sherin focused on the segments from the initial coding that were Student Science Ideas, with a focus on two dimensions. The first dimension focused on aspects of a student's science ideas that were discussed. Codes included Source (identifying teachers' talk about the origin of students' ideas), Action (identifying teachers' talk about students' gestures), Meaning (identifying teachers' talk about what students may have meant), and Content (identifying teachers' talk). The second dimension of the Level 2 codes focused on *how* the student's science idea was discussed. Codes included Describe (meaning an account of events), Evaluate (meaning talk that included some evaluative statement), and Interpret (meaning talk that worked to make sense of an idea). Luna and Sherin used the framework to analyze multiple video club meetings, allowing them to compare teacher noticing from video clubs over time. Their results showed that over time, teachers more commonly focused on Student Science Ideas, one aspect of their framework, and teachers increased the frequency of interpretations as they discussed Student Science Ideas. The framework provides a way for science education researchers to analyze noticing from a video club, specific to a science context and in a way that permits claims about changes in noticing over time.

Recent Articles on Noticing in Science (2021–2022)

Luna and Selmer (2021) Luna and Selmer (2021) propose connections between research on noticing and formative assessment. Considering Dini et al. (2020), they claim there are commonalities between noticing and formative assessment but argue that the two are not interchangeable. Instead, the relationship is dynamic, meaning teacher noticing is central to formative assessment. The purpose of the research was to deconstruct a teacher's noticing and make it visible, working from a space of formative assessment, to better understand responding aspects of noticing (e.g. Jacobs et al., 2010). Based on an analysis of 29 pedagogical response interview excerpts and prior research on teacher noticing, Luna and Selmer created a framework with four dimensions: "(a) when it occurred, (b) whom it was directed toward, (c) what was noticed that preceded the response, and (d) what teacher action was involved" (p. 583). Dimension 1, *when* a pedagogical response occurred, included codes of During Artifact Creation, After Artifact Creation, Prior to Unit Completion, and In the Future. Dimension 2, focused on whom, includes Individual and Whole Group. Dimension 3, noticing that prompted pedagogical response, resulted in seven codes: Share Thinking, Clarify Ideas, Develop Conceptual Understanding, Support Ideas/Thinking, Build Connections Between Ideas, Engage in Problem Solving, and Experience the Activity as more manageable/understandable. Dimension 4 includes codes for the teacher's Action, meaning the pedagogical response that was done during the lesson or could happen in the future. Codes included Simplifying Instructional Tasks, Modifying Instructional Tasks, Adding Instructional Tasks, Pondering Big Conceptual Ideas of Units, Questioning/Re-voicing Students' Ideas, Using Visual Support, Providing Space for Students to Work, and Telling Students Information. This coding scheme was applied to transcripts to better understand one science teacher's noticing and gave researchers a way to quantify the aspects of noticing and responding related to the focus. A major contribution of this framework is that it provides the field of science education with a way to decompose the responding aspect of noticing (i.e. Jacobs et al., 2010). Furthermore, the framework provides a way to better analyze the interplay of formative assessment and noticing. Luna and Selmer (2021) found that "a formative assessment context situated outside of instruction can engage teachers in practice-based noticing" (p. 578) and the framework focused on responding can support teacher learning of responding.

Zummo et al. (2022) Zummo et al. (2022) integrate aspects of pedagogical content knowledge (Shulman, 1986) to provide a framework for analyzing secondary science teachers' noticing made via video annotation tools. The framework, which is composed of two coding schemes, was designed to refine existing analytic processes for noticing with a consideration of the Next Generation Science Standards and distinguishes science-specific noticing from noticing that is more general. With the framework, data were coded for noticing *type* and noticing *focus*. Noticing type included the codes of Attending, which referred to descriptive noticing, and Knowledge-Based Reasoning, with the categories of Interpreting and Responding. Interpreting was defined as noticing involving interpretation, evaluation, or analysis, whereas Revising was defined as noticing that suggested a change to an instructional practice. The framework also included codes to identify the focus of noticing, with the codes of Student, Content, and Practice. Student referred to noticing related to students' actions, thinking, or anything verbalized. Content referred to disciplinary science content, and Practice referred to teacher actions or pedagogical strategies. One contribution of this work is how the presented framework builds on the work of Barnhart and van Es (2015) with analysis that allows a more nuanced approach to their work on sophistication and complexity. Another contribution is that Zummo et al. were able to characterize noticing that was specific to science, finding a remarkably low number of annotations that were content-specific. These findings, from the framework, pointed to the difficulty in supporting science-specific noticing or possibly suggest that aspects of noticing in a large part may be non-subject specific.

Schwarz, Braaten, Haverly and Santos (2021) Schwarz et al. (2021) focus on the sense-making aspects of noticing to understand how elementary science teachers' interactions expand, maintain, or limit sense-making. Their consideration of teachers' responsiveness to students' thinking is considered from a sense-making model to provide a science narrative, which includes inputs within contexts, analyzing sense-making moments, and possible outcomes. Using the model to identify sense-making moments, the researchers applied a framework to analyze these moments, which included four main categories: Examples of Student Contributions, Examples of Teacher's Pedagogical Moves, Possible Consequences of Moment, and Possible Science Narratives. Within Examples of Student Contributions, the framework includes making assertions, sharing examples, raising questions, and proposes an analogy. Within Examples of Teacher's Pedagogical Moves, the framework includes asks questions, invites students' cultural knowledge and practices, connects, presses for reasoning. Within Possible Consequences of Moment, the framework includes expanding sense-making, maintaining sense-making, and shuts down sense-making.

Within Possible Science Narratives, the framework includes teacher-constructed narrative, co-constructed narrative, student-constructed narrative, and fractured narrative. The focus on how teachers interpret sense-making moments connects to research on noticing (e.g. Luna, 2018), particularly aspects of responding and how teachers make sense of moments before they respond. One contribution of this work is the emphasis on sense-making, which we contend is important as teachers consider the racial, linguistic, and cultural experiences of the students with whom they work. Identification and analysis of the sense-making episodes provided an opportunity for the analysis of the accompanying pedagogical moves and responses that teachers made and builds from an aspect of noticing that has received considerable attention (i.e. Jacobs et al., 2010).

Considering Analytic Noticing Frameworks for Science: Then and Now

An interesting aspect of the frameworks for the analysis of noticing in science education is that they all have roots in analytic frameworks from mathematics education, with much of the work in science education being written by people with expertise in mathematics education (e.g. van Es, Sherin). A main theme from our analysis points to the *prevalence of the continuity of ideas in frameworks from mathematics to science*. Furthermore, the articles in science were not nearly as well cited as those in mathematics (see Table 1). Additionally, we found it challenging to find frameworks for analyzing noticing that had been published in the last two years and, indicating a second theme that *noticing has not been analytically studied in science education to the same extent that it has been studied in mathematics education*. When considering articles that have more recently been cited in science education noticing, Luna emerges as a prominent researcher in the field, because the prevalence of the work and the emphasis on empirically expanding ideas of noticing within a science context. Luna and Selmer (2021) draw connections between noticing and formative assessment, Zummo et al. (2022) draw connections between noticing and pedagogical content knowledge, and Schwarz et al. (2021) draw connections between noticing and sense-making. Therefore, a third theme in the science education noticing literature, based on these recent studies, is the attempt to *draw connections between noticing and other aspects of effective teaching* (formative assessment, sense-making, pedagogical content knowledge) in analysis frameworks. We acknowledge that these findings may be different if we had selected works from authors who had not also been authors on papers addressing noticing in mathematics. There is considerable overlap in the authors, which we consider a finding in and of itself with respect to the study of this work. Finally, we continue to recognize that these are the conclusions drawn from the selected papers.

Discussion

The analysis of the included publications provides a unique contribution in that our process focused on the evolution of noticing across two content areas. Three main conclusions are drawn from the analysis, which may have been different had other articles been selected and analyzed: (a) frameworks in science education are frequently adapted from mathematics, (b) frameworks in science education are moving toward pairing noticing with aspects of effective instruction (formative assessment, sense-making, pedagogical content knowledge), and (c) frameworks in mathematics are increasingly including context and equity as considerations with noticing. These trends were evident in our sample of articles, based on thorough analysis. Analyzing noticing across content areas and over time permitted a more holistic outcome that revealed differences in trends. The following discusses each of these three key findings in detail, with a focus on how the findings may be critical to support teacher noticing.

Science Frameworks Adapted from Mathematics Frameworks

Science education articles were not as frequently cited as mathematics education articles; thus, we raise questions about why studying noticing in mathematics has been much more common than in science education. The frameworks in science are mostly adaptations of the mathematics frameworks (Barnhart & van Es, 2015). Some of this may relate to early work in noticing (i.e. Mason & Spence, 1999; Mason, 2002, 2011; van Es & Sherin, 2002). However, questions remain as to why the topic of noticing seems to have roots in mathematics to a much greater extent than in science education. Why have science education researchers not published their own frameworks for noticing at similar times and to the same extent as has occurred in mathematics? Is this because the mathematics frameworks are adaptable or acceptable as tools for use in science education, and therefore generating new frameworks is not necessary? We recognize that particular themes of study are more prevalent in some disciplines than others. For example, there is extensive work on the nature of science (e.g. Lederman, 2013, 2722 citations at the time of this publication) and far less emphasis on the nature of mathematics (e.g. Young-Loveridge et al., 2006, 71 citations at the time of this publication). Considering a similar phenomenon related to noticing raises questions about why the difference between mathematics and science.

Science Frameworks Trend Toward Effective Instruction

When analyzing the articles in science that were highly cited and more recent, the frameworks in science education are moving toward pairing noticing with long-standing aspects of effective instruction (formative assessment, sense-making, pedagogical content knowledge). Based on Luna and Selmer (2021), who focus on noticing and formative assessment, the trend in science education seems to describe noticing as an overarching structure that can pair with other aspects of effective instruction. The coupling of noticing in tandem with effective teaching practices raises questions about the extent to which noticing is necessary for aspects such as formative assessment, sense-making, and pedagogical content knowledge. What is the role and relationship among these various aspects and constructs within education? Is noticing a form of pedagogical content knowledge? As those in the field of science education continue to explore these facets, will other aspects of effective teaching, or what it means to teach equitably, merge? The trends identified in this study raise interesting questions about the future direction of noticing research in science, particularly given the trend that the science education noticing research has often followed the mathematics education noticing research foci.

Mathematics Frameworks Trend Toward Context and Equity

The increased focus on context and equity in noticing research aligns with Dindyal et al.'s (2021) comments on recent literature about noticing and mathematics education. In that work, many authors (e.g. Erickson, 2011; Louie, 2018; Louie et al., 2021; Shah & Coles, 2020; van Es et al., 2017; Wager, 2014) are cited who focus on the social and cultural constructions of noticing. Our synthesis of the literature supports the claims of Dindyal et al. (2021) using a systematic approach and also considers the longevity of noticing research, which allowed for analysis of the evolution of noticing. As mathematics noticing research moves toward a focus of equity and inclusion, we question how the frameworks used to analyze noticing may continue to shift. We argue that as the focus of teacher noticing evolves, so too should the mechanisms by which we assess noticing.

Considering Shifts in Mathematics and Science Frameworks

The focus on context and equity for frameworks in mathematics education (i.e. Louie et al., 2021) raises questions about how noticing frameworks in science may be related to equity. Likewise, the focus on aspects of effective teaching in noticing frameworks in science (e.g. Chan et al., 2021) raise questions about how noticing frameworks in mathematics relate to similar aspects. In other words, highlighting the differences in findings based on discipline does not mean those disciplines are limited to frameworks in their content area, but provides an opportunity to consider the variety of important aspects related to noticing and how the work in each discipline could be helpful in other disciplines. Given the greater overall number of citations in mathematics focused on noticing research and the development of the construct in science that was chronologically later, we encourage science education researchers to more deeply explore aspects of context and equity related to science education contexts; however, we also encourage the mathematics education community to continue to think deeply about the role of effective instruction in relation to noticing. If one goal of noticing is to equip teachers with a decision-making process that is fresh rather than habitual (i.e. Mason, 2002, 2011) to ultimately improve student understanding in mathematics, then the decisions that are made (i.e. Jacobs et al., 2010) based on what is attended to and interpreted should likely be implemented with a focus on effective pedagogical practices in addition to context and equity. We encourage researchers to continue to explore these focal perspectives with future work on noticing in both mathematics and science.

Further Considerations and Conclusion

We recognize that the 12 articles selected impacted the results of this paper, and we believe our research-based rationale for our selection yields an understanding of the limitations of the included articles and simultaneously explains why the selected articles were elevated. Additionally, we recognize that the authors of the mathematics and science articles are not mutually exclusive; however, reducing the selection to mutually exclusive article authors would have eliminated key publications and therefore would not provide data on the connected nature of noticing in mathematics and science, a key finding and point of this synthesis. Given the 12 articles, this paper contributes to the field of noticing in mathematics and science by providing an in-depth review of these articles and a synthesis.

Additionally, one could argue that science frameworks were adapted from mathematics frameworks because of the origination of many early works on noticing occurring in mathematics-specific contexts. To address this concern, we reference the roots of noticing, which many would argue were in professional vision (Goodwin, 1994) and taken up by Mason (2002). We agree that early articles in the early 2000s (i.e. van Es) were a catalyst for the movement toward studying noticing in mathematics; however, few researchers (if any) have overtly clarified the relationship between noticing research in mathematics and science or examined it across disciplines. Our contribution lies in actually studying this relationship, finding specific examples, and reporting on the specifics of the dynamic interplay between research in both content disciplines. Therefore, although the connection between frameworks in mathematics and science may perhaps seem like an obvious conclusion, we do not find any other research articles where this has been addressed and, thus, consider this a contribution of the work. Furthermore, it was not an inevitable outcome to adapt math frameworks rather than generate new science frameworks.

From our in-depth review, we conclude that frameworks in science education are frequently adapted from mathematics education and there is a trend toward pairing noticing with aspects of effective instruction (formative assessment, sense-making, pedagogical content knowledge), whereas many of the frameworks in mathematics education currently consider context and equity. The 12 articles included do not represent all articles in the field, but they serve as a means to better understand noticing from a cross-disciplinary perspective. The analysis of noticing in two content areas, mathematics and science, has received little attention in the research literature. This paper provides a window into the intersection of noticing in mathematics and science, with a specific focus on the analytic frameworks used, which is an important foundation for understanding and researching noticing.

Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Julie M. Amador and Tracy L. Weston. The first draft of the manuscript was written by Julie M. Amador and Tracy L. Weston, and both authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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