International Electronic Journal of Mathematics Education
2024, 19(2), em0773
e-ISSN: 1306-3030
https://www.iejme.com

MODESTUM

Research Article

OPEN ACCESS

Meaning-making systems: A multimodal analysis of a Latinx student's mathematical learning

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Citation: Morales Jr, H., Chval, K. B., DiNapoli, J., & Pizzi, T. G. (2024). Meaning-making systems: A multimodal analysis of a Latinx student's mathematical learning. *International Electronic Journal of Mathematics Education, 19*(2), em0773. https://doi.org/10.29333/iejme/14363

ARTICLE INFO

Received: 25 Sep. 2023
Accepted: 13 Feb. 2024

ABSTRACT

This article discusses multimodal practices in the context of teaching and learning and how this idea might inform and facilitate mathematical learning, especially for Latinx students. We discuss qualitative data drawn from a study of an elementary bilingual classroom (age 10 and age 11) in a Midwestern city (USA) that is exceptional because the students successfully do high-level mathematics. We describe one class episode and one student's use of multiple resources to create meaning. Through this we highlight the nature and relevance of multimodal practices for learning mathematics. This case highlights the necessity of creating environments, where students, especially those who have been historically excluded, use resources to make meaning and gain greater access to mathematics.

Keywords: multimodal teaching, multimodal learning, mathematical representations, geometry

INTRODUCTION

The purpose of this paper is to introduce and discuss a classroom episode that highlights how Latinx multilingual students can use multimodal resources to think, communicate, and build meaning for mathematics. This episode is unique because the teacher emphasized multimodal practices and created a multimodal community of practice with her students. Our goal is to show how Latinx multilingual students possess knowledge, strength, and resources to learn mathematics, and how multimodal communication can support that process.

Latinx Multilingual Learners & Mathematics

In mathematics education, Latinx[1] multilingual learners are commonly marginalized to suggest they receive mathematical knowledge passively and are hindered by perceived language barriers (Gutiérrez, 2017, 2018; Razfar et al., 2011). Such marginalization may stem from deficit perspectives that continue to undervalue the use of languages other than the language of instruction (e.g., English) in mathematics classrooms (Barwell et al., 2017; Planas & Setati-Phakeng, 2014). Despite recent attention, mathematics education reform movements have arguably ignored the needs of Latinx multilinguals and deficit perspectives have been normalized in many mathematical learning contexts (de Araujo et al., 2018; Moschkovich, 2015). In the classroom, these deficit perspectives can manifest as school teaching practices that ignore the linguistic, social, and cultural capital of Latinx multilinguals, which can adversely affect Latinx multilinguals' opportunities to develop mathematical meaning (Clarkson, 2007; Langer-Osuna et al., 2016; Razfar, 2013).

Supporting students to develop mathematical meaning has often involved discursive activities that require students and teachers to engage in more substantive mathematical discussions and collective practice (Bass & Ball, 2015). This emphasis on discourse may dangerously presume a shared collaborative language among multilingual Latinx students and teachers (Chval & Khisty, 2009; Moschkovich, 2015), and requires careful consideration of multiple modes of communication, including all language repertoires, symbolic tools, and multiple semiotic resources in the mathematics classroom to truly support Latinx multilingual students' learning (Avalos et al., 2018; de Araujo et al., 2018). This perspective draws on the idea that meaning-making is a practice

[1] The authors employ the term Latinx to embrace a more inclusive descriptor that captures the diversity encompassing gender, sexuality, gender nonconformity, and transgender individuals who associate themselves with a Latin descent.

that involves using language, bodies, communicative resources, tools, and artifacts in dynamically coordinated, interconnected, and entangled ways (Cenoz, 2017; García, 2017).

In their review of the literature, de Araujo et al. (2018) detailed the importance of multiple modes of communication for multilingual students' mathematics learning. A synthesized insight from this review showed that students engaging in multimodal practices, including both verbal and nonverbal moves, can help students communicate and develop mathematical meaning (Martínez & Dominguez, 2018; Turner & Celedón-Pattichis, 2011). Several research studies support this. For example, Dominguez's (2005) research showed that teachers' encouragement of multilingual students to use gestures to communicate mathematical reasoning helped support student learning. Similarly, in a case study, Shein (2012) found a teacher's pointing, representational, and writing gestures to be pivotal in multilingual students' active participation during mathematics error analysis tasks. Related, Cho et al. (2015) found that curricula can be designed to prompt multilingual students to communicate their thinking through discussion, journaling, and uses of technology. In another study, DiNapoli and Morales Jr. (2021) found that classroom environments can emphasize the usage of nonverbal mathematical tools like calculators and multiple representations to be used in conjunction with activities requiring perseverance in problem-solving. In their study in Australia, Warren et al. (2014) shed light on the risks of experiencing mathematics purely from a linguistic standpoint. They provided evidence that making pedagogical choices such as "using rich representations to connect mathematical concepts with subject-specific terminology" (p. 23) that recognize the interconnectedness of mathematical communication and representation are key in developing multilingual students' mathematics learning. In Canada, Takeuchi's (2015) year-long ethnographic study demonstrated that the use of multimodal resources such as multiple languages and physical and symbolic tools enhanced multilingual learners' participation in their mathematics classroom community. Further, Takeuchi's research showed that teachers should shift their thinking from a language-deficient lens. Rather, they should provide access to mathematics as well as instill a sense of belonging in their multilingual learners by recognizing them as multimodal users who can draw on their linguistic resources to tackle mathematically rigorous tasks. It is through these multiple modes of communication, or multimodal moves, that Latinx multilingual learners can leverage their ample resources to engage more deeply with mathematics. In the next section, we describe the tenets of multimodal teaching and learning in mathematics.

A Theoretical Framework for Multimodal Teaching & Learning

Communication can be conceptualized as all systems of creating meaning, or modes, that are structured, consistent, and socially distinctive methods of representation (Kress et al., 2001). There has been a tendency to presume that communication primarily revolves around linguistic proficiency, likely because of the central role that language plays in our lives. From a sociolinguistic perspective, language is considered one of the paramount semiotic tools, given its overt and innate nature as the primary means through which individuals make sense of phenomena, transmit values and beliefs, and initiate the socialization of children into the practices of a culture (e.g., Boaler, 2000; Halliday, 1993; Lave & Wenger, 1991; Schleppegrell, 2007; Vygotsky & Cole, 1978; Wells, 1999). However, this perspective has obscured the reality that there is indeed a multitude of communication modes, including such modes as gestures and actions (e.g., Avalos et al., 2018; Chapman, 1997; Garcia, 2017; García-Mateus & Palmer, 2017; Kress et al., 2001; Nunez, 2000; Wells, 1999). Moreover, all of these modes–including and together with language–express meaning and contribute to mathematics learning (DiNapoli & Morales Jr., 2020, 2021; Morales Jr. & DiNapoli, 2018; National Council of Teachers of Mathematics [NCTM], 2014, 2018; Steinbring, 2006; Morgan et al., 2014).

Learning involves an active process, where students engage in remaking the information and messages provided by teachers in the classroom. In this view, learning is the students' reshaping of meaning to create new meanings (Kress et al., 2001). This dynamic process of sign-making is devised, organized, and utilized based on social needs and practices (Halliday, 1985). According to this understanding, meaning arises as a result of choices made by individuals, whether it be in speaking, using gestures, making drawings, moving their body, or employing any available resource to communicate or represent meaning. Moreover, individuals can use multiple modes simultaneously in this process (Jewitt et al., 2001). Sense making further develops as students are afforded, through multimodal learning, opportunities to draw on multiple semiotic resources to engage with cognitively demanding mathematical tasks (Roberts et al., 2020). Further, engagement of multilingual learners with such tasks develops their ability to reason abstractly as well as allows them to actively participate in their multimodal communities (Wilson & Smith, 2022).

In addition, research using the sociocultural perspective on human development emphasizes that learning is based in the interactions among people and the practical actions or activities they engage in, actions mediated by signs and tools (Mercer et al., 2019; Vygotsky & Cole, 1978; Wertsch, 1991). Thus, the ability to use language (speech) empowers children by providing them with additional tools to tackle challenging tasks, restrain impulsive actions, strategize solutions to problems before implementation, and gain mastery over their own behavior. Signs and words primarily serve as a means for children to engage in social interactions with others. Subsequently, the cognitive and communicative functions of language (speech) lay the foundation for a novel and more advanced form of activity in children (Vygotsky & Cole, 1978). Language (speech or writing), therefore, moves from an operational function to a cognitive and communicative function thus becoming a mediating tool in constructing meaning of new ideas, including mathematical ideas.

While individual choice of modality is integral to the process of creating new meanings, modes of communication and representation are artifacts passed down from generation to generation. In terms of cultural history, the tools and associated practices within a user community play a significant role in carrying patterns of past reasoning. These elements can contribute to the formation of distributed intelligence patterns within activities. However, as these tools gradually fade from visibility, it becomes challenging to recognize them as vessels of intelligence. Instead, the intelligence is perceived as residing within the individual mind utilizing these tools (Pea, 1997).

Historically, the design of tools, artifacts, and representations mediates mathematical activity in such a way that students' meaning-making process forms into new and unique ways of representing mathematical texts. Other research that studied multilinguals in mathematics explored the role of resources to construct, negotiate, and communicate (spoken or written) about mathematics (e.g., Chval et al., 2015; DiNapoli & Morales Jr., 2020, 2021; Morales Jr., 2012; Morales Jr. & DiNapoli, 2018). These resources included linguistic resources such as the mathematics register and mathematical discourse (Celedon-Pattichis, 2003; Moschkovich, 2015). This multimodal approach goes beyond language, incorporating mathematical symbols and visual images to enhance the understanding of language in the context of teaching and learning mathematics. O'Halloran (2015) elucidates that mathematical symbols carry precise and condensed representations of mathematical ideas. Similarly, visual images assist in representing mathematical concepts and applying knowledge. The acquisition of the mathematics register does not occur passively through traditional mathematics instruction (Moschkovich, 2015). Instead, O'Halloran (2015) advocates for a multimodal literacy, which encompasses not only language but also mathematical symbolic notation and mathematical images, emphasizing the interrelations and integration of these three resources. Supporting the development of such multimodal literacy in educational settings can help the assumption of a shared language between teachers and multilingual learners fade away (Martínez & Dominguez, 2018).

MATERIALS & METHODS

Social & Cultural Context for Study

One of the authors recorded 119 mathematics lessons from Ms. Martínez's fifth-grade classroom (i.e., 10 and 11-year-old students) over the course of one school year. In addition, the researcher observed 66 of those mathematics lessons, taking detailed field notes on classroom processes and collecting student work. This careful record of interactions and processes helped establish the social and cultural context of the classroom.

The classroom was situated in a low-income neighborhood in a Midwestern city, one of the largest public-school systems in the United States. The neighborhood was also predominantly Latinx of Mexican descent and a place where Spanish and English were spoken regularly. The class included 24 students who represented a wide range of academic levels in mathematics content and proficiencies in Spanish and English. **Table 1** includes the data from a standardized mathematics test that was administered at the end of each school year and previously reported in Chval and Khisty (2009). The fourth-grade column indicates student performance prior to entering the study.

Table 1. Growth in one year (as measured by median grade equivalent on Iowa test of basic skills)

Comparison groups	End of fourth grade mathematics total	End of fifth grade mathematics total	Gain
Ms. Martínez's class (n=24)	4.3	6.1	1.8
Other fifth graders in Ms. Martínez's school (n=56)	4.6	5.8	1.2
District (n=23,479)	4.6	5.6	1.0
National norm	4.8	5.8	1.0

The initial study of Ms. Martínez's classroom was conducted to understand how her instruction, discourse, and classroom environment contributed to students' mathematics achievement (see Chval, 2012; Chval & Chavez, 2011; Chval et al., 2021; Chval & Khisty, 2009; Khisty & Chval, 2002; Razfar et al., 2011; for other aspects of her teaching). Ms. Martínez's Latinx students consistently made significant gains in mathematics achievement, as measured by standardized tests. Ms. Martínez consistently created opportunities for students to learn mathematical topics that were beyond the conceptual scope of many fifth-grade USA classrooms. Historically, Latinx students from low-income or working-class neighborhoods rarely or never get opportunities to make meaning of challenging mathematical ideas (Avalos et al., 2018; Secada, 1996). Ms. Martínez was proud of her students and confident that they could learn challenging mathematics if she used engaging instructional strategies and curricula–again, unusual for Latinx students in urban classrooms (Avalos et al., 2018; Secada, 1996).

Ms. Martínez established a learning environment in which students actively participated in mathematical problem-solving, collaboration, oral and written communication, justification, and independent thinking (see Khisty & Chval, 2002). A typical lesson involved students working in small groups to solve complex mathematics problems followed by students presenting solution strategies at the chalkboard for a whole-class discussion.

Ms. Martínez was an active participant at all times through her questioning strategies. As students worked in small groups and presented solutions to the entire class, Ms. Martínez required the use of multiple modes (i.e., gestures, pictures, representations, speech, writing, and calculator keystrokes) to communicate mathematical ideas, analyze the strategies of others, negotiate meanings, explain or extend what other students stated, and justify arguments. In every lesson, Ms. Martínez repeatedly asked students to explain the meaning behind the keystrokes, representations, and symbols they used. It was clear that Ms. Martínez had a discursive system in place by which she could socialize her students into a particular multimodal community of practice. See **Table 2** for some examples of common feedback that aimed to support communal multimodal practice.

Table 2. Sample feedback to support a multimodal community of practice

Students' activity	Teacher's feedback
Students write a narrative about their solution process.	"Why don't you make a sketch on the side, so I understand what you mean? Your sketches explain your words."
Students verbally describe their solution process.	"Keystrokes first. That shows me what it is you're thinking, how you look at the picture, and what your understanding is. If you do not give me that, I cannot look inside your head."
Students multiply lengths of two legs in a right triangle.	"What's really happening? I'm visualizing what is really happening when I take one leg times another leg" [Moving students to build meaning for calculation (i.e., visualizing resulting rectangle].
Students use symbols in their explanations.	"What does that symbol mean?"

Throughout Ms. Martínez's mathematics lessons, students drew upon many resources and modes of communication for making sense of mathematics. Ms. Martínez created a learning environment that fostered and supported multimodal learning. Consequently, another part of understanding the processes that make this particular classroom exceptional for Latinx students is to examine their mathematical practices from a multimodal perspective. We analyzed a writing sample generated by Juan, one of the students in the class, in response to a student presentation by Violetta, his classmate (pseudonyms).

Next, in the Results section, we analyze and discuss this episode to demonstrate the various resources and modes of communication Juan used to access mathematical ideas. Further, we present the ways in which he adeptly employed various modes simultaneously to construct meaning in the context of mathematics.

RESULTS

Juan's Work Through a Multimodal Lens

Towards the end of the academic year in April, the students were tasked with two problems. The first involved determining the perimeter of a three-quarter circle with a given area of 100 square centimeters. Conversely, the second problem required calculating the area of a three-quarter circle with a known perimeter of 100 centimeters. While students were already adept at solving problems related to the area and circumference of whole circles, the introduction to the three-quarter circle presented a new challenge. Students engaged in both individual and collaborative efforts to tackle these problems. All students successfully solved the first problem, while only Violetta managed to solve the second one. Consequently, Violetta volunteered to share her solutions on the board with the class. In her presentation, she illustrated a three-quarter circle on the board and detailed the calculator keystrokes used to solve the first problem (refer to **Figure 1**). Throughout the explanation, Violetta clarified the significance behind each keystroke, with references to STO, SUM, and EXC keys, which are integral to the calculator's memory system.

100	÷	3	=	×	4	=	÷	π	=
$\sqrt{x}$	×	2	=	STO	×	π	÷	4	×
3	=	SUM	EXC						

Figure 1. Violetta's calculator keystrokes for first problem (Chval & Khisty, 2009)

The following is a transcription of Violetta's presentation of the first problem. We share Violetta's work (see also Chval & Khisty, 2009) because it became the object of Juan's multimodal practice.

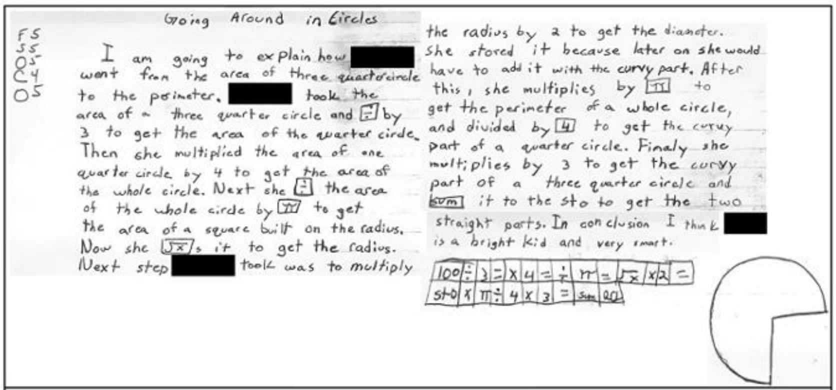
> Violetta: We are going to find the perimeter of the three quarter-circle. The area of the … the area of the three quarter-circle are 100 square centimeters. Now, we are going to go backward from the area to the perimeter. One hundred divided by three equals the area of one quarter-circle. Multiply by four to get the area of the whole circle. Divide by pi to get the area of the square built on the radius. You take the square root to get the radius. And then you multiply by two to get the diameter. Then we store it [a reference to the calculator's memory]. Then we multiply by pi to get the circumference of the circle. Then we divide it by four to get the quarter-circle. Then we multiply by three to get the curvy part of the three quarter-circle. Then we sum it, sum it to memory [another reference to the calculator's memory]. So, we can get the circumference, the perimeter, of the three quarter-circle.

Following Violetta's presentation of her solution to the first problem and the ensuing class discussion, Ms. Martínez instructed the students to compose a narrative about Violetta's presentation of the first problem. In the subsequent section, we will analyze Juan's narrative regarding Violetta's handling of the first problem.

A Multimodal Analysis of Juan's Writing

In response to his teacher requesting a written description about Violetta's presentation of problem 1, Juan wrote the following narrative (see **Figure 2**–Violetta's real name has been redacted). For ease of reading, we include the transcribed text of Juan's narrative below his written work in **Figure 2**. Several factors played a role in shaping Juan's comprehension of the problem, with the classroom environment standing out as a significant contributor. This classroom environment not only prompted students to tackle intricate mathematical problems but also emphasized effective communication of their thought processes. Juan's engagement with the problem manifested through his written expressions, starting from the assignment of the problem and continuing as he worked on solving it. Violetta's verbal explanations also played a crucial role in enhancing Juan's understanding. However, it's essential to acknowledge that dialogue is just one facet of a broader array of modes influencing

Juan's learning. Tools and artifacts, such as mathematical representations, calculator keystrokes, and geometric visuals, sometimes operate in the background, making them less visible yet integral to the meaning-making process. In our analysis, we focused on understanding the interrelationships, specifically among four modes of semiotic mediation: Juan's mathematical writing (written text), calculator keystrokes (mathematical symbols), Violetta's presentation to the class on the same problem (written and spoken text), and the depiction of the three-quarter circle (geometric figure).


Going Around in Circles

I am going to explain how [redacted] went from the area of three quarter circle to the perimeter. [redacted] took the area of a three quarter circle and ÷ by 3 to get the area of the quarter circle. Then she multiplied the area of one quarter circle by 4 to get the area of the whole circle. Next she ÷ the area of the whole circle by π to get the area of a square built on the radius. Now she √x's it to get the radius. Next step [redacted] took was to multiply the radius by 2 to get the diameter. She stored it because later on she would have to add it with the curvy part. After this, she multiplies by π to get the perimeter of a whole circle, and divided by 4 to get the curvy part of a quarter circle. Finaly she multiplies by 3 to get the curvy part of a three quarter circle and sum it to the sto to get the two straight parts. In conclusion I think [redacted] is a bright kid and very smart.

100 ÷ 3 = x 4 = ÷ π = √x x 2 =

STO x π ÷ 4 x 3 = sum

Going Around in Circles

I am going to explain how Violetta went from the area of three quarter circle to the perimeter. Violetta took the area of a three quarter circle and ÷ by 3 to get the area of the quarter circle. Then she multiplied the area of one quarter circle by 4 to get the area of the whole circle. Next she ÷ the area of the whole circle by π to get the area of a square built on the radius. Now she $\sqrt{x}$s it to get the radius. Next step Violetta took was to multiply the radius by 2 to get the diameter. She stored it because later on she would have to add it with the curvy part. After this, she multiplies by π to get the perimeter of a whole circle, and divided by 4 to get the curvy part of a quarter circle. Finaly [sic] she multiplies by 3 to get the curvy part of a three quarter circle and SUM it to the STO to get the two straight parts. In conclusion I think Violetta is a bright kid and very smart.

Figure 2. Juan's narrative of Violetta's presentation (Razfar et al., 2011)

We propose that Juan actively constructed meanings as he navigated seamlessly from the written text to Violetta's spoken discourse, to the geometric illustration, and to the calculator keystrokes, with no predefined sequence. In this dynamic process, Juan employed a diverse array of signs to compose his written text. Each mode played a role in shaping his interpretations as he crafted his text, and reciprocally, the written text evolved into a mode itself, influencing Juan's understanding. To compose his narrative, Juan needed to formulate meanings regarding how the three modes of signs–Violetta's verbal explanations, the geometric figure, and the calculator keystrokes–interrelated to create coherent mathematical ideas.

Juan's writing was categorized into three sections: determining the area of the whole circle, finding the diameter of the circle, and calculating the perimeter of the three-quarter circle. This segmentation not only organizes the data but also identifies the diverse modes of communication available to Juan as he crafted his text and the types of meanings he constructed in this multimodal process. Each table encompasses Violetta's spoken explanations from her presentation to the class, the keystrokes documented by both Violetta and Juan on the board or in Juan's writing, and the visual representations of the three-quarter circle referred to by Juan and Violetta in their explanations.

Part 1: Determining Area of Whole Circle

Our analysis commences with an examination of Juan's written text, specifically focusing on his approach to determining the area of the entire circle. Juan transformed Violetta's statement, "one hundred divided by three equals the area of one quarter-circle," into his own rendition: "Violetta took the area of a three-quarter circle and divided by three to get the area of the quarter circle." Notably, Juan assigned equivalent meaning to both the "one hundred" (Violetta's statement) and the area of the three-quarter circle (Juan's written expression). Furthermore, Juan incorporated the keystroke symbol " ÷ " to articulate his mathematical reasoning. His use of the "÷" keystroke implies an association between the term "divides" and the corresponding keystroke. Collectively, these observations suggest a possible mapping between the calculator keystrokes and Juan's written text (see **Figure 3**). For instance, whenever Juan employs the phrase "to get" in his text, it corresponds to the keystroke symbol "=". Conversely, one could infer that Juan has assigned the equal symbol the meaning of "to get."

While Juan incorporated only the image of the three-quarter circle, it's plausible that he engaged mental imagery encompassing the three-quarter circle, one-quarter circle, and the complete circle as he developed his understanding. Juan solved problems involving various forms of circles over the course of a month and Ms. Martínez had repeatedly encouraged him to visualize the related images while solving these problems. In essence, Juan had a strong conceptual history for solving problems involving circles with the support of multiple modes such as student presentations, geometric figures, keystrokes, and written and spoken text. For example, when Violetta said, "multiply by four to get the area of the whole circle," she actually guides her peers, including Juan, in forming an image of four quarter-circles forming a whole circle. In **Figure 3**, we see that only the first geometric figure (three-quarter circle) was evident in Juan's writing, but clearly other two images of circles were evident in Juan's thinking.

Mode	Description
Violetta's Talk	"The area of the three-quarter circle are 100 square centimeters. Now we are going to go backward from the area to the perimeter. One hundred divided by three equals the area of one quarter-circle. Multiply by four to get the area of the whole circle."
Keystrokes	100 ÷ 3 = × 4 =
Geometric Figures	
Juan's Writing	"I am going to explain how Violetta went from the area of the three quarter circle to the perimeter. Violetta took the area of a three quarter circle and ÷ it by 3 to get the area of the quarter circle. Then she multiplied the area of one quarter circle by 4 to get the area of the whole circle."

Figure 3. Determining area of whole circle (Source: Authors' own elaboration)

Part 2: Finding Diameter of Circle

Upon determining the area of the circle, Juan proceeded to divide it by pi. In a prior lesson, Juan was given a circle with a 10-centimeter diameter inscribed within a square given a side length of 10 centimeters. This square was subdivided into four equal squares constructed along the circle's radius.

Through various classroom activities, Juan deduced that constructing four squares on the radius resulted in an overestimation of the circle's area, while three squares led to an underestimation. Guided by Ms. Martínez, Juan developed the concept that constructing a square on the radius and then multiplying by pi yielded the accurate area of circles. Consequently, for Juan, dividing by pi geometrically signified determining the area of the square constructed on the radius. In addition to the geometric representation, Juan used Violetta's keystroke representation that was connected to the geometric representation with the use of gestures, speech, and writing. As a result, when Juan was asked to write about Violetta's presentation, he began to combine these modes to communicate his understanding (see **Figure 4**).

Mode	Description
Violetta's Talk	"Divide by pi to get the area of the square built on the radius. You take the square root to get the radius. And then you multiply by two to get the diameter. Then we store it." [A reference to the calculator's memory.]
Keystrokes	÷ π = $\sqrt{x}$ × 2 = STO
Geometric Figures	
Juan's Writing	"Next, she ÷ the area of the whole circle by π to get the area of a square built on the radius. Now she $\sqrt{x}$s it to get the radius. Next step Violetta took was to multiply the radius by 2 to get the diameter. She stored it because later on she would have to add it with the curvy part."

Figure 4. Finding diameter of circle (Source: Authors' own elaboration)

In our analysis, it becomes evident that Juan adeptly integrated keystroke symbols (e.g., ÷, x) into his narrative in a manner that aligns grammatically and syntactically with his explanation. Juan employed varied tenses throughout his narrative when recounting Violetta's actions, such as "she $\sqrt{x}$s [square-roots] it," "she stored it," and "she would have to add it." Contrary to the misconception that writing is merely a symbolic representation of speech, Wells (1999) argues that writing is a complex mental function involving deliberate multimodal action. Both speech and writing convey the same underlying meanings; however, writing serves as a problem-solving situation, attempting to visually represent the meanings communicated in speech. Juan's writing exemplifies this complexity as he juggles his written words ("area of a square built on a radius") with Violetta's spoken words, the keystrokes, and the geometric image of a quarter circle, all converging to represent the area of a square built on a radius.

Part 3: Calculating Perimeter of Three-Quarter Circle

Juan and Violetta derived the length of one-fourth of the circumference by dividing the circumference of the whole circle by four. Violetta referred to this segment as the "curvy part." Subsequently, both students multiplied this length by three to obtain the "curvy part" of the three-quarter circle, geometrically represented in **Figure 5**. Juan and Violetta incorporated four keystrokes related to the calculator's memory system—"SUM," "STO," "EXC," and "RCL." The "STO" key was employed by both students to store the value of the diameter (or two radii) of the circle in the calculator's memory system. Juan and Violetta diverged slightly in their approaches; Juan added his curvy part "to the STO," while Violetta added hers "to memory." Despite both using the "SUM" key in their keystroke text to combine the diameter value with the “curvy part,” they retrieved the diameter value differently. Juan used “RCL” (recall), whereas Violetta used the “EXC” (exchange) key, yielding the same result. This distinction is noteworthy, indicating that although Juan borrowed the term “curvy part” from Violetta’s presentation, his utilization of a different keystroke demonstrates an independent understanding rather than a mere replication of Violetta’s verbal explanation or keystrokes.

Mode	Description
Violetta’s Talk	“Then we multiply by pi to get the circumference of the circle. Then we divide it by four to get the quarter circle. Then we multiply by three to get the curvy part of the three quarter-circle. Then we sum it, sum it to memory. [Another reference to the calculator’s memory]. So, we can get the circumference, the perimeter, of the three-quarter circle.”
Keystrokes	× | π | ÷ | 4 | × | 3 | = | SUM | EXC
Geometric Figures	
Juan’s Writing	“After this, she multiplies by π to get the perimeter of a whole circle, and divided by 4 to get the curvy part of a quarter circle. Finaly [sic] she multiplies by 3 to get the curvy part of a three-quarter circle and SUM it to the STO to get the two straight parts.”

Figure 5. Calculating perimeter of three-quarter circle (Source: Authors’ own elaboration)

In this context, it is evident that each student employed distinct geometric images to illustrate the combination of the circular curve and the perpendicular radii, presenting the process in unique linguistic styles. Juan integrated the “curvy part of the three-quarter circle...and the two straight parts” (radii). In contrast, Violetta articulated the combination as “... the curvy part of the three-quarter circle. Then we sum it, sum it to memory.” The memory she referred to contains the previously stored value of the diameter of the circle. Despite their differing expressions for the three-quarter circle, both Juan and Violetta utilized the same keystrokes, except for the final ones (RCL and EXC). Notably, both students demonstrated an understanding that the diameter is twice the radius and can be geometrically represented by perpendicular radii connecting the three-quarter circle. Juan, adeptly navigating between varied representations of the diameter, successfully balanced spoken text, keystrokes, geometric images, and his own written text. Once again, the historical context of the classroom activities, interactions, and the utilization of multiple modes played a pivotal role in shaping Juan’s comprehension.

DISCUSSION

Juan’s active participation in Ms. Martínez’s classroom, involving discussions, explanations, writing, and presentations, is crucial for the success of multilingual learners in mathematics. Students tend to naturally gravitate toward their first language when they are tasked with reasoning mathematically (Clarkson, 2007). Creating a multimodal community allows students to draw on their linguistic resources to communicate their mathematical thinking and to reason with one another as they encounter more complex mathematical problems. Juan’s case reinforces this idea by demonstrating that students can acquire academic language and grasp mathematical concepts concurrently (Barwell, 2005; Moschkovich, 2015). Juan’s meaning-making was highly embedded in and dependent on the classroom’s social interactions (forms of language) and in the cultural practices that emphasized symbol systems, gestures, and drawings as well as reading, writing, listening, and speaking. Juan’s meaning-making also illustrates the benefits of a multimodal community of practice, which Ms. Martínez had developed in her classroom in which learning was inseparable from the multimodal activities, context, and culture (Cobb & Yackel, 1996; Hansen-Thomas, 2009). The activity with which Juan was engaging was not a typical activity for a fifth-grade American classroom. Yet, in this case, the combination of Ms. Martínez’s teaching prowess and Juan’s enthusiasm to use multimodal tools allowed for a fifth-grade student to naturally explore algebraic ideas–a truly special outcome. A fair criticism of Juan’s case is that the equals sign is being used as an operator or answer-getter and not a symbol of equivalence (Knuth et al., 2006). However, we contend that these students are still being primed for success in algebra based on their experiences.

Educators can learn from Ms. Martínez and can support such practices by consistently affording students opportunities to engage in challenging mathematical tasks as well as facilitating classroom environments, where linguistically diverse communication is fostered (Turner & Celedón-Pattichis, 2011). By implementing multimodal practices that foster sense making, Ms. Martínez helped dissipate the assumption of a shared language between teachers and her multilingual students. Such practices disrupt the dependence on use of (English-only) spoken language that often marginalizes students who are still in the process of becoming proficient in the language of instruction (Martínez & Dominguez, 2018). This disruption can then make way for the engagement of multilingual students like Juan and can challenge them to become active participants in their mathematics classrooms. Furthermore, curriculum, whether it is embedded in everyday lessons or in extra-curricular activities, must consider students’ cultural and linguistic backgrounds (Razfar, 2013). Rather than seeing these as barriers, our education system should be utilizing language and culture as valuable resources for learning mathematics, much like Ms. Martínez illustrated in this paper.

Our examination of Juan’s meaning-making as a system of multiple modes of resources and communication tools helps illustrate the dynamics of the learning process (Cenoz, 2017; García, 2017). Furthermore, Juan’s case directs us to reconsider how classrooms are organized and how instruction can be implemented to support Latinx multilingual students' learning in mathematics and disrupt marginalizing practices (Chval et al., 2021). The mathematical practices in Ms. Martínez's classroom illustrate the importance of leveraging the learning capital students bring to and develop in classrooms (Langer-Osuna et al., 2016). In this classroom, students had many avenues for expressing their knowledge and the teacher could more easily assess students' learning and adjust accordingly. Lampert (1991) posits that teachers have the responsibility to find the language and symbols that students and teachers can use to enable them to talk about the same mathematical content. Juan's case illustrates how students can utilize numerous modes as tools for learning and meaning construction. Juan was engaging with Violetta's communication about her calculator keystrokes, which was helping foster his algebraic thinking (Driscoll, 1999). The distributed knowledge in the calculator also provided Violetta the tools to support her own algebraic thinking and self-efficacy development. Moreover, Juan was able to develop mathematically because his teacher made multimodal teaching important for learning. This illustrates that teachers can leverage multiple languages spoken in their classrooms to assist students as they participate in a mathematics discourse community (Musanti & Celedón-Pattichis, 2013; Willey, 2013). In all, this suggests and reiterates that educators need to utilize multiple modes in teaching, select mathematical tasks that enable the use of multiple modes, and encourage students to utilize multiple modes themselves (de Araujo et al., 2018).

Such a multimodal approach will additionally enhance the learning of Latinx bilingual students through practices that intertwine everyday linguistic features and mathematical register resources in a dialogic manner, aiming to create meaning (Garcia-Mateus & Palmer, 2017). This is especially important for students (in this case, Latinx students) learning mathematics in the language of instruction since they often need other ways to communicate mathematically in their first language (DiNapoli & Morales Jr., 2020, 2021; Morales Jr. & DiNapoli, 2018). Therefore, students' multimodal communication in mathematics learning is particularly crucial because one of the key pillars of improving the teaching and learning of mathematics is engaging students in rich, sophisticated construction of content knowledge via all forms of communication (Avalos et al., 2018).

This study on multimodal meaning-making has several implications. The equitable education of Latinx multilingual learners continues to be an imperative research topic in the international field of mathematics education. Globally, there is a rise in the number of countries that have increased linguistic diversity in their mathematics classrooms (Barwell et al., 2017). Moreover, ways to effectively educate students who are learning the primary language of instruction continues to be an international issue in mathematics education research as the language of instruction often differs from that of students' first language (de Araujo et al., 2018). Populations from several countries worldwide suffer from this kind of bias and marginalization in their mathematics education systems. For instance, in the United Kingdom, bilingual or multilingual students may belong to mathematics classrooms where the English-only ideology is promoted and the use of other languages in those classes may not be accepted (Barwell, 2005). This monolingual ideology that undervalues other languages is also present in other countries such as Catalonia-Spain and South Africa (Planas & Setati-Phakeng, 2014). The consequence of such ideology is the isolation and marginalization of students whose first language differs from the language of instruction. This type of marginalization leads to limited access to mathematics and disengagement from meaningful participation in the classroom, which inevitably hinders progress in learning.

To effectively address equity (or lack thereof) in mathematics education we must begin with "language-rich environments, cognitively demanding mathematical tasks for all students, and multiple modes of communication" (Chval & Chavez, 2011, p. 261). By doing so, educators can begin to move away from the deficit perspective that their multilingual students lack knowledge and instead implement multimodal practices to develop their students' ways of communication. It is through such multimodal pedagogy that teachers can allow all students equitable access to mathematical content. Multimodal learning allows for students to access diverse semiotic resources to develop their sense making (Roberts et al., 2020). This type of access improves students' competencies to tackle more cognitively challenging mathematical tasks. Engaging multilingual students in such tasks provides opportunity for them to reason abstractly (Wilson & Smith, 2022).

To appropriately support these students in their reasoning skills, teachers need to foster multimodal communities in their classrooms to allow for the productive contribution of multilingual students to their mathematics community. Discussion and talk about language should be as important as the mathematical content. Building on student knowledge through classroom participation moves us away from the deficit lens that multilingual students are only passive observers in mathematics classrooms. The active participation of students provides affordances for language development as well as mathematical thinking, which is crucial to multilingual learners' success in mathematics (Chval et al., 2021).

CONCLUSIONS

Multilingual students often face an unfortunate and persistent tendency to limit their access to and utilization of various modes in mathematics classrooms. This is evident in the inadequate incorporation of calculators, drawings, manipulatives, writing, and student presentations, particularly in schools with limited resources (de Araujo et al., 2018). For Latinx multilingual students, this multimodal limitation suggests a deficit perspective, which assumes Latinx students receive mathematical knowledge passively, are constrained by language barriers, and are not capable of multiple modes of learning (Gutiérrez, 2017, 2018; Razfar et al., 2011; Rubel, 2017). Latinx multilingual students and other language learners face a restriction in expressing their thoughts and are deprived of alternative avenues to comprehend mathematics due to the seldom use of multiple modes of communication. This study of an elementary bilingual classroom, and our focus on one class episode and one student's use of multiple resources to create mathematical meaning, helped show how multimodal practices in teaching and learning can better inform and facilitate mathematical learning, especially for Latinx students. This study highlights the necessity of creating environments where students, especially those who have been historically excluded, use resources to make meaning and gain greater access to mathematics. If educators neglect these alternative modes of communication or fail to contemplate their integration into the classroom, then we may leave unnoticed the complete array of resources that students could potentially harness to construct meanings and comprehend mathematics.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that this study complies with the ethical parameters adopted by the Institutional Review Board at the University of Illinois at Chicago (Protocol #: H-98-1036; Approval Date: 30 November 1998). Written informed consents were obtained from the participants.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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