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Emergent Bilingual Middle Schoolers' Syncretic Reasoning in Statistical Modeling

Structured Abstract

Background/Context: Bi/multilingual students' STEM learning is better supported when educators leverage their language and cultural practices as resources (Daniels, & Westerlund, 2018), but STEM subject divisions have been historically constructed based on oppressive, dominant values (Dei, 2010) and exclude the ways of knowing of non-dominant groups. Truly promoting equity requires expanding and transforming STEM disciplines (Bang & Medin, 2010)

Purpose/Objective/Research Question/Focus of Study: This article contributes to efforts to illuminate emergent bi/multilingual students' ways of knowing, languaging, and doing in STEM. We follow the development of syncretic literacies in relation to translanguaging practices, asking: *How do knowledges and practices from different communities get combined and reorganized by students and teachers in service of new modeling practices?*

Setting and Participants: We focus on a seventh-grade science classroom, deliberately designed to support syncretic literacies and translanguaging practices, where computer science concepts were infused into the curriculum through modeling activities. The majority of the students in the bilingual program had arrived in the United States at most three years prior to enrolling, from the Caribbean and Central and South America.

Research Design: We analyze one lesson that was part of a larger research practice partnership focused on teaching computer science through leveraging translanguaging practices and syncretic literacies. The lesson was a modeling and computing activity co-designed by the teacher and two researchers about post-Hurricane María outmigration from Puerto Rico. Analysis used microethnographic methods to trace how students assembled translanguaging, social, and schooled practices to make sense of and construct models.

Findings/Results: Findings show how students assembled representational forms from a variety of practices as part of accomplishing and negotiating both designed and emergent goals including sense-making, constructing, explaining, justifying, and interpreting physical and computational models of migration.

Conclusions/Recommendations: Implications support the development of theory and pedagogy that intentionally make space for students to engage in meaning-making through translanguaging and syncretic practices in order to provide new possibilities for lifting up STEM learning that may include but is not constrained by disciplinary learning. Additional implications for teacher education and student assessment practices call for reconceptualizing schooling beyond day-to-day curriculum as part of making an ontological shift from prioritizing Math, Science and CS disciplinary and language objectives as defined by and for schooling, toward celebrating, supporting, and centering students' diverse, syncretic knowledges and knowledge use.

Executive Summary

Schools often expect emergent bi/multilingual students to engage with named languages (e.g., English, Spanish), disciplines (e.g., math, computer science [CS]), and modalities (e.g., writing, reading, programming) within discrete classes. However, these schooled divisions were constructed based on historically oppressive, dominant values (Dei, 2010), and leave little space for students' multifaceted ways of knowing. The concept of *Syncretic literacies* offers a way to blur the boundaries between disciplinary and community practices, creating space for transformative learning. Similarly, *translanguaging* theory offers a way to blur the boundaries between and hierarchies associated with language categories. We present analyses of a bilingual (Spanish-English) middle school science class. Lesson design and instruction, guided by a syncretic orientation, invited students to leverage translanguaging practices for a modeling and computing activity about post-Hurricane María outmigration from Puerto Rico. Of the 27 students, most had arrived in New York recently from the Dominican Republic, Mexico, and Central America. We looked empirically at how students and teachers combined and reorganized knowledges and practices from different communities in support of building and making sense of statistical models as the lesson unfolded.

Data included fieldnotes, audio recordings, photos of ongoing activity, and classroom artifacts. Microanalyses considered the different social and cultural *forms* that students recruited (including discourse tools, materials, and inscriptions), and the *functions* these forms served in addressing goals of the activity. As activity unfolded and new understandings developed, new goals emerged, giving students opportunities to discover new functions for existing forms, or the need to recruit new forms. These shifting relations between forms, functions, and emergent goals illuminated interconnections between students' engagements with models, computational and mathematical reasoning, and their knowledge of migration, in relation to translanguaging practices. The latter drew attention to students' flexible semiotic practices and how these practices in part *constituted* and *became resources for* syncretic literacies. Rather than centering the development of STEM and English/Spanish language objectives, analyses traced how students organized forms from a variety of practices to serve functions in the accomplishment of local modeling and sense-making goals.

Findings show how students assembled representational forms from a variety of practices as part of accomplishing and negotiating both designed and emergent goals including sense-making, constructing, explaining, justifying, and interpreting physical and computational models of migration. Boaler and Greeno (2000) description of a *dance of disciplinary and human/conceptual agency* discussing these findings. Disciplinary agency relates to actions constrained by rules of the discipline—here, mathematics and the Scratch coding schema. Conceptual agency is shaped by participants' understandings of what they are reasoning about and for. Throughout the episodes we see this dance in relation to the development and use of particular modeling forms and practices for the accomplishment of collective, emergent goals. Students' syncretic development and use of these forms and practices to support and transform their learning of modeling encompassed not only school disciplines (math, science, and computational thinking) but also everyday literacies. Implications of these findings support both the development of theory and pedagogy that intentionally make space for students to engage in meaning-making through translanguaging and syncretic practices to provide new possibilities for lifting up mathematical and CS learning that may include but is not constrained by disciplinary learning. There are additional implications for teacher education and student assessment practices. For teachers to be

able to cultivate generative and collaborative ecologies that democratize STEM learning and doing, they must be trained in ways that do not silo knowledge - currently distinct from how most teacher education programs treat apprenticeship (i.e.: distinct classes on supporting language development, methods of science teaching, and so forth). Likewise, changes are implied for assessment and accountability frameworks which constrain how teachers are allowed to operationalize and define science learning. Our findings call for reconceptualizing schooling beyond day-to-day curriculum as part of making an ontological shift from prioritizing Math, Science and CS disciplinary and language objectives as defined by and for schooling, toward celebrating, supporting, and centering students' diverse, syncretic knowledges and knowledge use.

Introduction

In recent years, research has shown that bi/multilingual students[1] are better supported when educators leverage their language and cultural practices as resources for STEM learning and development (Daniels, & Westerlund, 2018). At the same time, many scholars and practitioners have argued that truly promoting equity requires expanding and transforming STEM disciplines themselves (Bang & Medin, 2010): STEM subject divisions have been historically constructed based on oppressive, dominant values (Dei, 2010) and exclude the ways of knowing and doing STEM of non-dominant groups. Even culturally relevant STEM instruction runs the risk of incorporating students' cultures and languages only as scaffolds towards mastery of static, master-narratives of "science" abstracted from local context (Calabrese Barton, 1998) and of "Academic English" (Flores, 2020).

In contrast, this article takes seriously emergent bi/multilingual students' ways of knowing, languaging, and doing in STEM. We do so through design for, and analysis of *syncretic literacies* (Gutiérrez, 2014), and *translanguaging practices* (García & Li Wei, 2014). Syncretic literacies "bring together and reorganize different, contradictory and discrete cultural practices that are generally incompatible or in tension" (Gutiérrez, p. 49). Just as a syncretic approach dismantles traditional hierarchies among domains, translanguaging practices, or the ways individuals deploy their full linguistic, social, and semiotic practices in sensemaking, specifically challenges the boundaries around named languages, legitimizing emergent bi/multilingual students' fluid and dynamic language practices (García & Li Wei, 2014; Otheguy et al., 2015). In episodes of learning analyzed below, we trace the development of syncretic literacies in relation to translanguaging practices in a science class where computer science concepts were infused into the curriculum through modeling activities, deliberately designed to support these syncretic literacies and translanguaging practices. Rather than investigate how or the extent to which students used their language and cultural practices to engage in “Computer Science,” “Math,” “Science,” “English,” “Spanish,” and so on, we aimed to use a syncretic design strategy and analytic lens to challenge the idea that all learning should serve advancement toward disciplinarily defined developmental aims. In other work, we have described our approach to syncretic design (see Radke et al., 2020). Here, we look empirically at how students’ syncretic practices develop and shift. We are guided by the question: *Given a syncretic orientation that encourages and leverages translanguaging, how do knowledges and practices from different communities get combined and reorganized by students and teachers in the services of new modeling practices?*

STEM and emergent bi/multilinguals: Moving towards a syncretic orientation

As education research and practice seeks to engage bi/multilingual learners, we must reckon with the harmful deficit-based lenses with which academic disciplines have historically viewed, and often continue to view, these populations (Valencia, 2010). For example, educators, especially in STEM fields, often have lower expectations for emergent bi/multilingual students, assuming they must learn English before they can engage with complex content (Moschkovich, 1999). However, we know that bi/multilingual students and communities engage in sophisticated scientific inquiry and bring their language, meaning-making practices, and unique experiences to STEM classrooms (Poza, 2018; Ramirez & Celedon-Pattichis, 2012; Vogel et al., 2019).

In this paper we focus on these students’ physical and computational modeling practices. Modeling, outlined by many as a core epistemological and representational practice in the sciences (Lehrer & Schauble, 2005) and a “language” of science (Giere, 1988), includes the cumulative processes of developing, testing, comparing, and refining representations of phenomena, events, or processes. From this perspective, the goal of modeling is the creation and coordination of representational objects with mathematical or computational abstractions; for computational modeling this is expressed in computer programs (Giabbanelli & Jackson, 2015). Standards bodies have identified modeling and representation as goals for science instruction in and of themselves (NGSS, 2013). At the same time, modeling is embedded in practices of problem solving, interpretation, and communication about real world phenomena (Greeno & Hall, 1997). Teaching modeling in ways that disconnect the practice of modeling from the social, political, and or cultural structures of phenomena of interest can run the risk of creating a chasm between how learners are expected to engage with models and how they might leverage them for sense making. We acknowledge an associated core tension in fostering this kind of meaning-making with respect to modeling real world phenomena in the context of academic disciplines. On the one hand, schools are both intellectually and administratively set up to "discipline" learning and academic practices (Siskin, 1991). This is true in STEM as well as the way that schooling keeps language practices separate, with different spaces or times of day devoted to different kinds of "academic" language, and/or named languages (e.g., Sánchez et al., 2017). On the other hand, genuine student learning is both grounded in contexts or disciplines and involves knowledge across contexts including lived experiences outside of school (Gutiérrez, 2014). Further, individuals always bring their full set of semiotic resources to their activity, no matter the context (Otheguy et al., 2015; Lin, 2019). Our study emerges from this tension; we aim to look beyond disciplinary, or "practice-linked" learning. Especially in STEM education, there has been the common assumption that students must learn academic or professional disciplinary practices in the most "authentic" manner possible (e.g., NRC, 2007). However, Philip & Sengupta (2020) point out that the drive toward authenticity is, in fact, a drive toward the very inequitable structures and practices we claim to be improving by broadening participation in STEM. In other words, if professional and academic STEM practices, institutions, and ideologies marginalize and deny access to nondominant groups, why would making STEM learning settings more authentic to those practices, institutions, and ideologies fix the problem? STEM education might do better by empowering students to build on both community and disciplinary resources to develop their own STEM agendas and problem-solving tools. This requires an ontological shift in determining both what counts as STEM and how we study STEM learning. Thus, we take up syncretic and translanguaging theories to resist the artificial boundaries made by dominant institutional agendas.

Syncretic literacies

We seek to understand how diverse, typically segregated, often asymmetrical in status, practices can be "organized to connect and reorganize practices so as to engender new forms of knowledge and expertise that embody characteristics of the best of [all] sets of practices, albeit in new forms" (Gutiérrez & Jurow, 2016, p. 572). In most STEM classrooms, learning is treated as what Gutiérrez (2014, drawing on Engeström, 1999) called "vertical"—oriented towards increasing compliance with standards for knowledge, practices, and language within a narrowly defined discipline, generally dictated by academic institutions or professional groups. Building on the meaning of syncretism which describes attempts to reconcile conflicting philosophical or religious systems by creating something new, Gutiérrez (2014) explained that syncretic literacies do not just bring together literacies "that are generally incompatible or in tension with one another" (p. 49) or co-opt "everyday[2]" literacies to support more formal, or "scientific" ways of thinking. Instead, they create something new, and provide opportunities for meaningful and transformational learning. In contrast with vertical learning promoted through school standards, syncretic literacies embrace and value "horizontal learning," or how learners develop and integrate knowledge across contexts, including lived experiences outside of school.

Very deliberately, this syncretic orientation flattens hierarchies that treat disciplinary practices as more sophisticated and therefore more valuable. For marginalized youth, in particular, this is critical, as their home and community practices have been systematically disparaged or erased in schooling, and thus the burden usually falls on them to navigate boundary crossings between these disparate spaces (Vossoughi & Gutiérrez, 2014). The design goal here is to provide a learning context where the boundaries between disciplinary and community practices—including but not limited to ways of communicating, sense-making, and modeling—are less rigid, and more expansive definitions of what counts as science and computational thinking are possible. Looking at syncretic literacies from these angles highlights its compatibility with translanguaging.

Translanguaging as theory and pedagogy

Traditional notions of bilingualism which employ colonial and modernist viewpoints privilege nation-state standard language categories (e.g., English, Spanish) over the practices of individuals and communities of speakers. These views have had consequences in language policy and education, most notably for *language minoritized and racialized* people whose language practices may not conform to or be perceived as conforming to those of the dominant group in society. Developed as a corrective theory which resists these oppressive and reductive views, and in contrast with 'code switching' which conceptualizes language practices as merely selecting from among externally defined categories and named languages, *translanguaging* refers to how (bi/multilingual) people fluidly deploy resources from an integrated linguistic repertoire without regard to named language standards or categories, to make meaning and communicate (Otheguy et al., 2015).

Translanguaging has been conceptualized as a tool for dismantling monoglossic and raciolinguistic ideologies that negatively impact the educational experiences of students often officially labeled “English Learners,” whom we refer to as emergent bi/multilinguals. Monoglossic ideologies refers to the belief that “legitimate linguistic practices are only those enacted by monolinguals” (García & Li Wei, 2009, p. 114). Raciolinguistic ideologies refer to the ways that white listening subjects perceive deviance in the language of racialized people, no matter their actual performance (Flores & Rosa, 2015). The white listening subject does not refer specifically or exclusively to individual white listeners, but rather to an ideological position that polices language for standardization or propriety/appropriateness. Thus, in STEM contexts, it is not only white listeners, but also things that embed a positionality rooted in whiteness like language tests and "academic language of science" frameworks that narrow what constitutes legitimate participation in scientific discourse, particularly for bi/multilingual students. Translanguaging has facilitated a way to reimagine learning that *starts* from students and their language practices, rather than simply imposing the dominance of named languages that are typically associated with power (Otheguy et al., 2015). However, despite this potential, translanguaging has most often been taken up in service of meeting static disciplinary objectives, treating them as unproblematic. In response, some scholars have emphasized its critical, transgressive potential, pushing translanguaging’s definition beyond deployment of linguistic resources to include how people orchestrate social, embodied, and semiotic resources embedded in people and the environment (García & Li Wei, 2014; Hua et al., 2017). These conceptions of translanguaging help us disrupt the boundaries around STEM disciplines. Even though white listening subjects may not have the tools to perceive what language minoritized, racialized bi/multilinguals do in STEM classrooms as ‘real science,’ students orchestrate their lived and local meaning-making practices together with a range of resources—including texts, concepts, language of school—to engage in inquiry about the world.

The Emergent Goals Framework

We wed the concept of translanguaging with syncretic literacies, considering syncretism that not only brings together often asymmetric “everyday” and “scientific” concepts, but also that which arises in translanguaging practices that combine language and social practices no matter their different statures in schooling. A syncretic orientation in instructional design necessarily supports learners’ translanguaging practices, eschewing normative boundaries and hierarchies between cultural ways of knowing and the “official” language practices associated with them.

As we are interested in new practices that emerge in syncretic design, we trace their development using Saxe’s (1991) Emergent Goals Framework. This framework builds on constructivist and sociocultural lenses that treat learning as a sense-making activity that takes place in goal-directed activity (e.g., Piaget, 1970; Vygotsky, 1978). In two parallel strands of analysis, the framework examines how 1) new goals emerge as collective activity unfolds, and 2) how cultural artifacts (or forms) take on meaning in the context of activity and how they are deployed to accomplish emerging goals (their functions). Together, these strands illuminate how, as learners take up cultural forms in the service of goal-directed activity, new goals emerge, and new functions may be discovered for existing forms. Likewise, new forms may be recruited for accomplishing new goals, and new goals may become available given newly constructed forms and functions. Tracking the forms used along with the functions they serve, and how this relationship shifts in the context of emerging goals allows insight into the development of new forms of activity.

Our adaptation of Saxe’s framework is particularly useful for a study of syncretic STEM literacies, as we are interested in the diverse, often neglected forms participants may recruit as well as the unexpected (by instructors) functions these forms may serve. For Saxe, “forms” were material or symbolic artifacts that have developed cultural meaning in social activity. For example, currency obtains its particular value in a community that agrees on its worth and how to use it. In the local context of a board game, rules may stipulate that a slip of paper labeled "10" is worth the same as two labeled "5", and that they may be exchanged for one another. However, while most players may follow these rules, players who do not use base 10 addition[3] might not find this exchange function to be relevant. In our analysis, while dominant forms and functions were present in instructional design and goals, our syncretic orientation does not assume a particular set of form function relations to be installed as the endpoint of learning; rather, students may organize forms from a variety of practices to serve functions in the accomplishment of locally sensible goals that emerge and are, in part, shaped by the forms deployed.

METHODS

Research setting and participants

Data for this study came from a research practice partnership (RPP; Penuel et al., 2015) which originated in 2017; teachers from three public middle schools in New York City came together with university-based researchers to develop, implement, and study curricular designs to address problems of practice and answer research questions related to supporting the participation of bi/multilingual learners in New York City's Computer Science for All (CS4All) initiative. Practitioners were interested in integrating computing into their subject area classes (versus hosting stand-alone CS courses). Researchers offered up translanguaging theory and pedagogy as potential frameworks for collective thinking about the design of learning environments for teachers' bi/multilingual learners that encouraged teachers to make connections across disciplines and to students' interests and communities in syncretic ways (see Radke et al., 2020). In this paper we visit a seventh-grade science classroom in a transitional bilingual program where Lucy (names of teachers, students, and places are pseudonyms) worked with researchers to integrate computing into her curriculum as part of supporting students' engagement with, among other science concepts, modeling and interpreting statistics. As per the school's language allocation policy, Lucy conducted this class in Spanish, but she and her students used language flexibly throughout. The majority of the students in the bilingual program had arrived in the United States at most three years prior to enrolling, from the Caribbean and Central and South America.

A resident of the school's neighborhood and of a Dominican background (like most of her students), Lucy was a certified bilingual teacher in her 17th year teaching. Lucy, Sara (Author 2), and Chris (Author 4) co-designed a unit that investigated the long-term impacts of 2017's Hurricane María based on student interest in the topic. Both Sara and Chris identify as White, university-based researchers from outside the students' and teachers' school and home communities; Sara identified as bilingual, an English and Spanish speaker. Lucy taught lessons in this unit weekly, from October to June. Given the fluid nature of the roles in an RPP, researchers often co-taught/co-planned with teachers. As the partnership deliberately grappled with tensions relating to power and positionality that permeate participatory research (Bang & Vossoughi, 2016), teachers often took on tasks that would be traditionally regarded as research, such as analysis and presenting at conferences, in our efforts to decenter "academic" ways of knowing and researcher control. The lesson analyzed here was guest-taught by Sara.

Design

The student practices discussed here emerged in a classroom designed to promote students' participation in modeling practices across disciplines—science, math, computer science, and social studies—and to treat all of students' language, reasoning, and sense-making resources as valuable towards learning and participation. To achieve these goals, Lucy, Sara, and Chris co-designed a unit wherein students would create physical and computational models of the social impacts of Hurricane María, which had devastated Puerto Rico the prior school year. In the weeks before the focal lesson, students had shared their own and families' experiences with storms, considered what kinds of data the public would want to know, analyzed infographics of recent hurricanes, interviewed a Puerto Rican scientist, and read news articles to learn about effects of violent weather systems. As the unit transitioned to using the Scratch programming environment for modeling, Lucy and Sara decided to have students begin by analyzing a teacher-created model. While three students in her class had prior experiences using Scratch in their elementary schools, before the class period featured in this article, the other students had only used Scratch one other time as part of Lucy's class. Lucy, still hesitant to teach with Scratch, accepted when Sara offered to run the lesson.

Data and Analysis

Data for this study includes fieldnotes, audio recordings, photographs, and material artifacts including student work and lesson slides. Focusing on interactions in which physical and computational model-building was a primary activity, methods of multimodal microanalysis (Goodwin, 2010) were used to follow the unfolding nature of student and modeling practices and statistical sensemaking in talk and moment-to-moment interactions. Analysis was conducted individually by the first two authors, and in data sessions with project team members to account for alternative explanations (Jordan & Henderson, 1995).

In order to address the research question investigating how knowledges and practices across communities were combined and reorganized by students and teachers, analysis tracked emergent goals and shifts in form function relations. This allowed us to develop a detailed account of participants' unfolding activity and the resources (cultural artifacts) recruited. We hold ourselves accountable to how participants oriented toward and took up, adapted, or rejected goals emerging from unfolding interactions with each other, grounded in the details of interaction available in the data. In like fashion, we identified forms constructed, recruited, and adapted by members in service of the emergent goals. In other words, while the interdisciplinary research group necessarily brought their own ways of seeing and identifying cultural forms (e.g., linguistic forms[4], conventional mathematical forms, gestural forms), we examined how participants jointly formulated (for themselves and each other), then used meaningful artifacts as a way of mutually orienting toward goal-directed activity (McDermott et al., 1978). To this end, we treated as *forms* assemblages of linguistic, physical, and material constructions that constituted conceptual themes that took on meaning to accomplish some goal. For example, in Episode 1 below, the verbal explanation, along with the placement and movement of blue cubes to represent a percentage of a migrant population, all together constituted a form which served the function of modeling Puerto Rican migration because of Hurricane María. In this way we incorporated our syncretic and translanguaging framing in making sense of participants' activity and microgenetic development. Then, we looked across the episodes to make sense of the forms and functions and their shifting relations to analyze how students' sense-making and modeling practices drew on intertwined literacies.

FINDINGS

The lesson began with students sharing statistics they had identified from articles about the long-term impacts of Hurricane María. Then, Sara projected (in Spanish), "After Hurricane María, 400,000 Puerto Ricans left the Island. Of those, 43% went to the state of Florida and 9% went to New York." Students were asked to work in pairs to build a physical model they could use to hypothetically teach a sibling or cousin about the statistic. They were given colored cubes and a paper map of Puerto Rico and the US mainland with New York and Florida highlighted.

Episode 1: Rochy and Max: "Estos cuadritos significan uno cada uno, uno porciento"

This episode begins after Rochy and Max called Sara over. She re-read the instructions on the worksheet, then asked what they could do with it and the cubes (pointing at each).

[82] Rochy: Puede esto represent forty-one ((pointing to one of the cubes))
Rochy: This could represent forty-one ((pointing to one of the cubes))
[83] Max: Ponerlo en el color que van.
Max: Put it in the color where it goes
[84] Sara: Ok, ¿Cómo?
Sara: Ok, how?
[85] Rochy: Like, blue over there. No, déjalo like, like, put like like forty-three percent in in Flórida ((Places a blue cube on the image of Florida))
Rochy: Like, blue over there. No leave it, like, like put like forty-three percent in Florida ((Places a blue cube on the image of Florida))

As part of this classroom activity, students were asked to create a model to fit information about a past event. To do so, Rochy and Max had to accomplish the connected emergent goal about how to coordinate the worksheet and plastic cubes in order to create a representational form that functioned to model the migration to Florida and New York after Hurricane Maria. Rochy, the first to verbally use the word "representar," ("to represent,") [82] signaled his coordination of the materials he was given with the statistic. In this first utterance Rochy suggested 41 rather than 43, but soon corrected himself. When Sara asked, "¿Cómo?" ("How?") Rochy took this up as an explicit request to demonstrate the function of the cubes and explaining his modeling choices emerged as a new goal. Rochy named how the cubes would function to depict the proportion of people who migrated to Florida as part of accomplishing both the emergent goal of creating his model for the statistic and defending it.

Rochy and Max built the representational form by bringing the physical materials together with talk and action, their coordination of resources and practices superseded boundaries of named languages. Specifically, Rochy produced an environmentally coupled gesture (Goodwin, 2007) with words that would be recognized as Spanish and English in a single utterance. In other words, physical gesture, material world, and verbal talk mutually elaborated each other; the sum of these communicated what no individual parts could. In this exchange the cube was assigned a *representational function* in relation to the modeling activity (i.e., the cube would correspond to the percentage of migrants to Florida). Then, together with talk and gesture, the cube and the map became a new, usable *form* for the actors involved. That is, overlaying physical materials with talk, gesture, and the contextual specifics of the statistic created a more complexly meaningful form and served to accomplish the emergent goals of the modeling activity. As they continued to model together, Rochy and his partner Max discussed what a single cube and a collection of cubes could represent, and where to place cubes on the map.

[86] Sara: Ok. Put forty-three percent in Flórida. ¿Cómo representarías forty-three percent?
Sara: Ok. Put forty-three percent in Florida. How would you represent forty-three percent?
[87] Rochy: Cuarenta y tres blue
Rochy: Forty-three blue

Rochy took up Sara's question as a repair (Schegloff, 1997); he treated the repeated question, "¿Cómo...?" [84; 86] as a correction of the form he had offered for using a blue cube in Florida to represent the 43% [85]. In response, Rochy provided a new explanation that he would use "Forty-three blue," [87]. This constituted part of a new representational form in which each cube represented 1%, all together representing 43%. They continued to work for about eight more minutes until Sara asked them to share their model with another pair of students, Fabiana and Naomi. By then, Rochy and Max were using a new cube configuration for their representation. Fabiana and Naomi joined Rochy and Max to look at their final model (Figure 1). Fabiana began by noticing a blue cube with a divot on top labeled "5%." Note this cube was slightly different, physically, from the smooth-faced blue cubes that represented 1%. Additionally, the blue now represented migrants to New York, while red represented migrants to Florida.

[186] Fabiana: Ah, y ¿por qué colocas cuatro porciento si aquí es nueve?

Fabiana: Oh, and why did you put four percent, if here it's nine?

[187] Rochy: Claro. Porque, estos cuadritos significan uno cada uno, uno porciento. Uno sumas un cuatro porciento y este significa cinco ((pointing to the cube labeled 5%)), tu lo sumas y hay nueve porciento.

Rochy: Of course, because these little cubes mean one for each one, one percent. You add one up to four percent and this means five ((pointing to the cube labeled 5%)), you add it up and it's nine percent

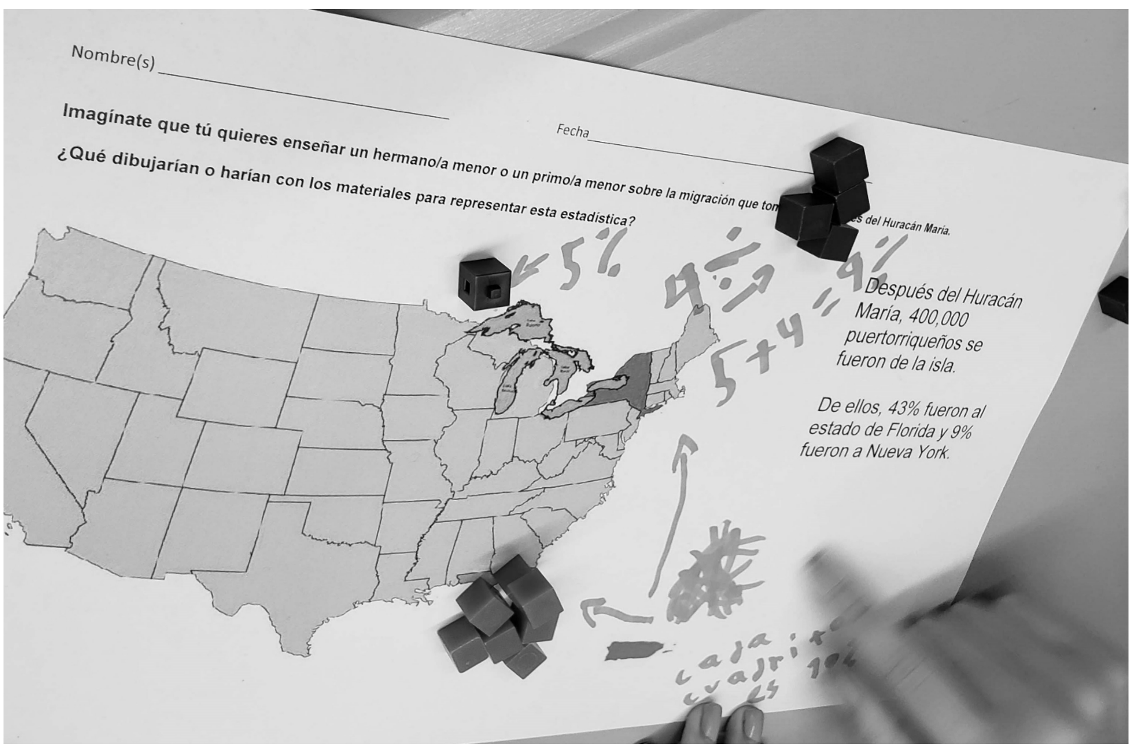
[188] Fabiana: Ah, okay

Fabiana: Ah, okay

[189] Rochy: Eso ((pointing to the red cubes on Florida)), cada cuadrito significa diez por ciento eh, eso es un cuarenta por ciento y esto es cuarenta y tres por ciento

Rochy: This, ((pointing to the red cubes on Florida)) each cube means ten percent um, this is a forty percent, and this is forty three percent

Figure 1: Rochy and Max's physical migration model. Arrows extending from Puerto Rico at the bottom right of the page point to Florida and New York. At the top, a blue cube with a small divot on top has been labeled "5%," and to the right 4 cubes have been labeled "4%." At the bottom of the page, the students placed seven red cubes on the state of Florida on the map. They wrote the label "cada cuadrito es 10%" or "each cube is 10%."



In this exchange, aspects of Rochy's model came under scrutiny, driven by the goal of completing the assigned task of comparing and contrasting different student-made models of the same statistical statement. Like Sara's earlier probes [84; 86] Fabiana's question [186] motivated an emergent goal for Rochy to be more precise in his modeling justifications, focusing on how Rochy had used the cubes in coordination with written notation (5%) to create a representational tool that modeled nine percent (migrants who went to New York). Rochy's environmentally coupled gesture and talk functioned to clarify that the divoted cube represented 5%, while each smooth blue cube represented 1%, so that together, they summed to 9% [187]. Rochy extended his explanation to include the red cubes that now represented 43% as well [189]. Fabiana's question helped to shape the emergent goal of justifying all the parts of his model – not just the one she questioned. We distinguish this goal from the earlier goal of explaining his modeling choices, in that justifications are arguments for reasonableness, in addition to articulating why or how something works. When he demonstrated the function of the cubes to Sara, Rochy explained how he imagined the model would work. With Fabiana, he both explained what each part of the model represented and gave reasons *why* his model was sensible. Rochy brought together talk, material artifacts, gesture, and mathematical notation; this assemblage constituted a new representational form to which both he and Fabiana referred throughout the excerpt.

Taken as a whole, this episode exemplifies the ways in which students became increasingly specific about what the physical objects meant in relation to one student model. We see what Lehrer and Lesh (2003) described as, "interacting systems of inscription and notation as students grapple with potential correspondences between the world and the emerging mathematical description," (p. 384). What's more, their translanguaging orchestrated talk, gesture, symbolic tools, and physical materials to build, ask questions about, explain, and justify the model. While each interaction was guided by an overarching instructional goal (excerpt 1: build a model; excerpt 2: share your model), other emergent goals (explaining and justifying) also shaped the ways in which Rochy and Max built and presented their model.

Episode 2: Discussing and unpacking teacher models

Students' choices about what to model foreshadowed key themes in the discussion later in the period when Sara presented her own models of the same statistics, both of which highlighted the process of migration, in contrast to students' models of the outcome of migration. The physical model used a 10-sided die to determine where to move cubes on the printed map. A roll of 1-4 would send a cube to a cup near Florida, approximating the 43% statistic. Otherwise, it was put in the "otros lados" (or "other") cup. This physical model corresponded to the computational model Sara presented in which, every half second, a cartoon person with a suitcase would appear and "migrate" from Puerto Rico, depending on a randomly assigned number from 1-100. Those assigned 43 or lower went to Florida, and the rest to a random location on the map. Both models applied statistical concepts such as randomness, ratios, and time-averages. While students may have had prior experiences with these ideas in other classes or settings, they had not been discussed in Lucy's class before. The models' deployment of these concepts provided affordances for discussing them, though they were not the explicit objective of the lesson of sense-making about and with models in a general sense.

In discussing their noticings, students focused on movement ("everybody is going to different places"), as well as the counters that kept track of the total number of migrants, how many went to Florida, and how many went to "other" places. Sara took up this latter noticing, asking what they could infer, "¿Por qué piensan que es así?" ["Why do you think that is?"]. Students took this up by shifting from sharing noticings to explaining what they saw on the computer screen. Despite Sara's focus on the process of the statistical simulation, their explanations were grounded in the social phenomena, shaped by their own emergent, sense-making goals.

[331] Rochy: Maybe because eh, está persona tiene familia en Florida, ¿no?

Rochy: Maybe because eh, this person has family in Florida, no?

[332] Sara: Esto puede ser una razón en la vida real, pero en el modelo, por qué hay más gente en otros lados que Florida. ¿Sí?

Sara: This could be a reason in real life, but in the model, why are there more people going to other places than Florida. Yes?

[333] Eddy: Uno puede inferir que ellos están yendo pa' otros lugares que Florida porque Florida está más cerca de Puerto Rico, y tal vez el Huracán lo impactó también

Eddy: One could infer that they are going to places other than Florida because Florida is closer to Puerto Rico, and maybe the Hurricane impacted there too

[334] Sara: OK. Esto puede ser como dije, una razón en la vida real por qué la gente decidió migrarse, pero en el modelo, ¿cómo está decidiendo la computadora que vamos a mandar gente a Florida o a otro lado?

Sara: Ok, this could be, as I said, a reason in real life why people decided to migrate, but in the model, how is the computer deciding that we're going to send people to Florida and not another place?

Both Rochy and Eddy responded in the context of the hurricane and the people impacted. These social justifications functioned to explain the migration to "other places" modeled by the program and represented by the statistic. Each time, Sara acknowledged their suggestion as valid "in real life," but attempted to repair their orientation to her question, pushing them to explain "in the model," [332; 334]. This reframing and repair indicate a tension between designed lesson goals and students' emergent sense-making goals. Sara distinguished two activity systems: real life and the computer model. Students' reasoning was acceptable in the first, but their answers did not explain what was happening in the second, and thus did not satisfy her question.

At this point Lucy focused attention back on the statistic, and Gabriela, another student, suggested that the percentage of people migrating to "other places" could be found by subtracting 43 from 100. Sara responded by writing this subtraction expression in the form of the vertical algorithm on the board, motivating the new goal to solve this problem. As part of accomplishing this goal, the class negotiated the correct operations to solve the problem while Sara recorded the mathematical notation on the board. This constituted a shift in the *form* of students' meaning-making assemblages (from social narratives explaining percentages to percentages as a notational form in a mathematical algorithm) as well as a shift in *function* (from reasoning about human movement to solving an arithmetic problem). They collaboratively accomplished the arithmetic operations and used the solution to make a quantitative argument about more people migrating to other locations than to Florida. After completing the calculations, students returned to social explanations for migrating to places other than Florida, incorporating the fact that there are more places other than Florida migrants might go, accounting for the remaining 57%.

Throughout this episode, students shifted their efforts to accomplish both designed lesson goals and emergent sense-making goals. This created an ebb and flow, or push and pull, between accepted mathematical, computational, or scientific arguments and social, often personally rooted, arguments for migration, where shifts were motivated by which emergent goals were the focus of participants' activity. Together, the teachers and students mobilized different representational forms, including social explanations and a collaboratively constructed subtraction algorithm, to achieve different emergent goals simultaneously, thus bringing together and reorganizing forms which teachers had initially treated as incompatible, (though not irrelevant). This led to a new way of understanding the migration statistic, embedding imagined experiences of migrants for statistical sense making not highlighted by solely quantitative interpretations.

Episode 3: Taking a closer look at the code

For the final activity of the period, students were given a handout with the Scratch code (in Spanish) for the computational model (Figure 2). They were asked to identify the part of the code that made their favorite part of the model work. At one table, Sara helped Katy and Eddy, who were collaborating to identify and explain the code that governed Katy's favorite portion of the program, "Cuando caminan" ("When they walk"). This action was represented in two different places in the code, depending on the random number generated for each "migrant," and Sara directed the pair's attention to both places, asking, "¿Cómo decide?" ("How does it decide?").

[410] Sara: Oh:: ok. Y cómo funciona este código, que unos van a Florida y otros van a una posición aleatoria. ¿Cómo decide?

Sara: Oh:: ok. And how does this code work, that some go to Florida and others go to a random position. How does it decide?

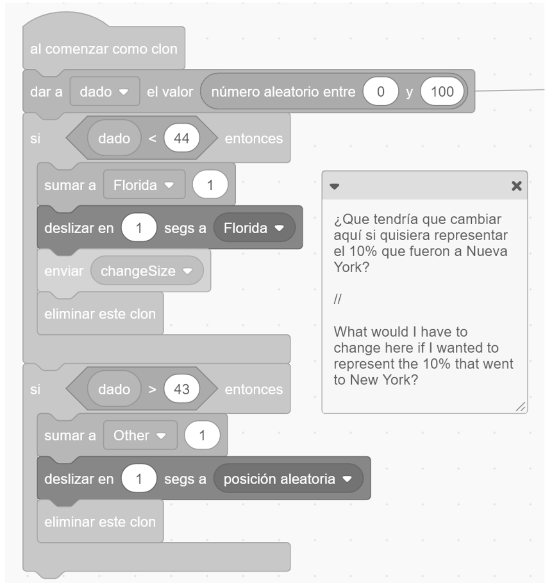
[411] Katy: Ehm, hay un dado aquí que dice (?)

Katy: Um, there's a dice here that says (?)

Katy took up Sara's question as a request to articulate another part of the code and its function within the program, zeroing in on a variable in the code labeled "dado" (die) as important to the program's operation [411], in direct reference to the physical die that sorted cubes into the Florida or "otros lados" cups in the physical model. Sara validated the importance of the die and, prompted students to explain how this block of code worked. This new emergent goal, linked to Sara's earlier questions regarding why more people went to places other than Florida when they watched the computational model run, brought together forms the class had previously developed (the die; the assemblage of mathematical and social explanation for migration to Florida vs other places) for the function of explaining the operation of the Scratch code.

This brief episode highlights how students brought together and adapted forms created during sense-making interactions across the lesson's modeling activities. Students' syncretic literacies emerged in particularly salient ways in this final activity which prioritized interpreting computer codes. They recruited and deployed academic and everyday discourses across named languages, social reasoning about migration, procedural algorithms, and mathematical notation. In this way, we see that making sense of computer code as used in computational modeling can benefit from and prompt syncretic conversation.

Figure 2. A screenshot of the code (written by Sara with Scratch's Spanish interface) that Katy and Eddy identified as responsible for making their favorite part of the program work. Alongside the code are comments that the instructors included to orient students.



Discussion

In our analysis, we focused on students' assembly of *representational forms* (Saxe, 1991), supported by translanguaging practices, as part of accomplishing both designed and emergent goals including sense-making, constructing, explaining, justifying, and interpreting physical and computational models of migration. Students' syncretic development and use of these forms and practices drew not only on knowledge commonly associated with school disciplines (math, science, and computational thinking) but also everyday literacies to support and transform their learning of modeling. The first episode demonstrated how students assembled and justified increasingly refined representational forms such as Rochy and Max's model, which strategically brought together verbal language, mathematical notation, gesture, and different physical materials. In the second, students coordinated resources and actions across domains (subtraction algorithms, social explanations), developing forms that were then used in the negotiation of emergent tensions in learning moments, creating opportunities to attend to the experiences of migrants not made visible by the statistic. The third example highlighted how students mobilized forms developed together in previous activities as resources for the next activity. Across all three, we see how translanguaging practices were critical in students' syncretic sense-making and agentic setting of emergent goals.

While there were certainly lesson goals related to schooled disciplines, our syncretic design and analysis did not hinge on targeting school or everyday practices or literacies. Instead, we assumed that syncretic (and translanguaging) practices exist, and it is in looking and making space for them that syncretic literacies may emerge. Boaler and Greeno (2000), building on Pickering's (1995) ideas, described a *dance of disciplinary and human/conceptual agency* in the learning of mathematics. Disciplinary agency relates to actions constrained by rules of the discipline—here, mathematics and the Scratch coding schema. Conceptual agency is shaped by participants' understandings of what they are reasoning about and for. Throughout the episodes described above, we see this dance in relation to the development and use of particular modeling forms for the accomplishment of collective, emergent goals. For example, it was in the push and pull of the second episode, when Sara's designed lesson goals felt in tension with students' socially driven explanations of "why" migrants went to one place or another, that a syncretic literacy began to emerge. In this dance of agency, seen in shifting form function relations over the course of class activity, students collected and strategically assembled heterogeneous meaning-making around social narratives, quantitative relationships, and physical and computational models. Students made sense of scientific and mathematical ideas and tools on their own terms, and a syncretic orientation and translanguaging theory allowed us to illuminate the ingenuity learners applied to modeling when their full semiotic and reasoning repertoires were considered.

Categories developed for schooling, often through studies of schooling, can be damaging when used to evaluate students' reasoning (Patel, 2015). Rather than naming student activity as "mathematical," "scientific" or "computational thinking" (or evaluating whether it was a "good" version of any of these), this study was driven by our commitment to understand "what reasoning is going on here, and how?" This necessitated an ontological shift from prioritizing Math, Science and CS disciplinary and language objectives as defined by and for schooling, toward valorizing diverse, syncretic knowledges. Modeling is a cross cutting practice that can be brought to many domains. These practices are centered in different ways across school disciplines, as: e.g., an applied form of mathematics in school math (Cobb & Moore, 1997; Gould, 2010), a tool for prediction, theory-building, and empirical argument in the sciences (Schwarz et al., 2009), a form of representation in history or social studies (Berson & Berson, 2007), or a tool for expression in language arts (Bruce & Levin, 2003). However, central to all its uses, modeling, as presented to students, often privileges 'real' numbers over local knowledge (Ben-Zvi & Garfield, 2004). While models may attempt to capture social realities (e.g., migration), they often rely on intermediate quantitative data (e.g., statistics) to do so. The students' choices about which of these ideas to prioritize highlight that statistical sense-making is not a hierarchical construction in which first students reasoning about a statistic and then reason with said statistics in relation to social phenomena (Radke et al., 2019). Rather, students were simultaneously making sense with and about the statistics embedded in the prompt and the underlying social phenomenon to produce a physical model of migration.

This study provides insights into how to recognize and privilege mathematical and CS student participation and learning rooted in students' semiotic practices and community knowledges. It also highlights the value of supporting and designing for students' syncretic activity as a critical part of learning. We advocate for the development of theory and pedagogy that intentionally make space for students to engage in meaning-making through translanguaging and syncretic practices. In observing and acknowledging how students engage these practices, teachers can understand the diverse paths students take to make connections and explore concepts. In this way, translanguaging and syncretic practices are not to be solely employed and valued as practices that serve a vertical learning function, but to promote students' conceptual agency for expansive learning that may include but not be constrained by disciplinary learning.

There are also implications for teacher education. Like K-12 schooling, teacher education often silos knowledge and practices into disciplines, a consequence of programs structuring degree and certificate requirements into distinct classes on language development, literacy, STEM teaching methods, and so on. For teachers to learn to cultivate generative and collaborative ecologies that democratize STEM learning and doing, their training might include opportunities to notice and build on students' and their communities' language practices and syncretic literacies. Our project team has begun to develop and study an approach to professional development that encourages teachers to plan curricula and learning environments that go beyond simply meeting disciplinary standards by "valuing community knowledge as it overlaps with and exists alongside knowledge from computing and the disciplines" (Vogel et al., 2020, p. 5). In this approach, teachers take stock of students' and their communities' funds of knowledge (Moll et al., 2005), and ways of languaging and computing to express, make meaning, and take action in our world, and then ask themselves: "What conversation could code become a part of?" Such changes in teacher education, however, must be accompanied by changes to broader assessment and accountability frameworks which currently constrain how teachers are allowed to operationalize and define language and science learning. Our findings call for reconceptualizing schooling beyond day-to-day curriculum as part of making an ontological shift from prioritizing Math, Science, and CS disciplinary and language objectives as defined by and for schooling, toward celebrating, supporting, and centering students' use of diverse, syncretic knowledges.

NOTES

1. We use the terms “emergent bi/multilingual” and “bi/multilingual” learners to honor students’ language knowledge and problematize English as most valuable. Additionally, the word “emergent” captures that language learning is a dynamic, continuous process (García & Kleifgen, 2018).

2. We agree with Moschkovich (2002), who argued that “academic” and “school” practices are, in fact, the “everyday” practices of many. However, in this article we use the term “everyday” as a stand-in for “non-school,” acknowledging the status differentials between what is commonly called “everyday” and “school’ practices.

3. Following our syncretic orientation, we emphasize that this example makes use of base 10 addition, and that other communities and cultures, including the Oksapmin people studied by Saxe (1991), may have their own sophisticated counting and arithmetic systems.

4. We note that the terms form and function have also been used in linguistics fields, where they have been used to refer to voice sounds, gestures, and written symbols and the purposes these fulfill in relation to each other as in formal linguistics (Cruz-Ferreira & Abraham, 2011) or in social interaction as in functional linguistics (Halliday, 1973). Our use of these terms, while related to these traditions, draw directly from Saxe’s Emergent Goals Framework (1991).

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