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Integrating STEM, Language, and Visual Literacy for Multilingual Learners

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Abstract

While multilingual students in K-12 classrooms are steadily increasing, they are significantly underrepresented in STEM (Science, Technology, Engineering, and Mathematics) at the post-secondary level and workforce (National Academies of Sciences, Engineering, and Medicine, 2018). This paper contributes to narrowing this gap by proposing an integrated STEM, language, and visual literacy approach. The first part of the paper explains the theoretical perspectives and their connections to each other. In part two, the authors share how the integrated approach works, using concrete classroom examples such as sense-making, deepening STEM learning, developing disciplinary language and discourse, and using multimodal communication. STEM educators will be inspired to implement appropriate multilingual student support strategies to create culturally responsive instructional activities that empower students and leverage multimodal communication, motivating them to pursue advanced study and add new perspectives traditionally excluded in STEM.

Keywords: visual literacy, inquiry, culturally responsive teaching, multilingual learners, STEM

Introduction

Classrooms in the United States have become more diverse, with students from different linguistic and cultural backgrounds. The National Center for Educational Statistics (2022) shows that the number of English Language Learners (ELLs) was 5.1 million in the fall of 2019, representing approximately 10.4% of the entire student body in K-12 settings. One out of four students is projected to be an ELL across the nation by 2025 (National Education Association, 2020).

Many different terms, such as ELL and emergent bilingual, are used to address this group of linguistically and culturally diverse students. In this paper, the authors use the term “multilingual students” to describe these students’ linguistically rich profiles and shift the focus away from English.

With a growing population of multilingual students in schools, a top concern for educators is how to support their academic success. The authors center their discussion on engaging and supporting multilingual students in the interdisciplinary subject of STEM (Science, Technology, Engineering, and Mathematics). STEM education has traditionally been seen as an apolitical space in which students learn facts and theories and conduct hands-on experiments leading to politically neutral findings. However, studies show that multilingual students have a lower interest in STEM, lower persistence rates to pursue STEM at the higher education level, and a lower sense of belonging in STEM classes (National Academies of Sciences, Engineering, and Medicine (NASEM), 2018). Consequently, they are significantly underrepresented in STEM fields at the post-secondary level and workforce. This paper addresses the need in the field by promoting an innovative approach that integrates visual literacy, content, and language to engage multilingual students in culturally responsive STEM inquiry.

Theoretical Perspectives

This paper is based on a professional development project funded by the Library of Congress (LOC) Teaching with Primary Sources (TPS) Midwest Regional Grant. With the support of the grant, the authors,

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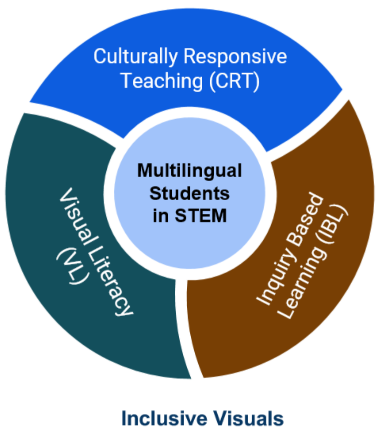
who are the project team, developed professional learning experiences for both pre- and in-service STEM teachers focusing on selecting and using inclusive visuals to address the needs of multilingual students. "Inclusive visuals" is a term coined by the authors to integrate key features of three theoretical perspectives on which the project was grounded: culturally responsive teaching, visual literacy, and inquiry-based learning. Even though each theoretical perspective varies in its components and applications, the authors' discussion centers on the connection with multilingual students' STEM teaching and learning. A visual representation of how the three perspectives connect through inclusive visuals is shown in Figure 1.

Figure 1
Theoretical Perspectives



Culturally Responsive Teaching

The disappointing outcomes of marginalized populations in STEM problematize the perception that STEM is neutral and makes culturally responsive teaching (CRT) an essential theoretical perspective and approach to working with multilingual students (Ladson-Billings, 1995). CRT uses "the cultural characteristics, experiences, and perspectives of ethnically diverse students as conduits for teaching them more effectively" (Gay, 2002, p. 106). CRT is founded on the assumption that "when academic knowledge and skills are situated within the lived experiences and frames of reference of students, they are more personally meaningful, have higher interest appeal, and are learned more easily and thoroughly" (Gay, 2002, p. 106). That is, when STEM teaching and learning experiences are situated within students' funds of knowledge (González et al., 2005) and lived experiences, they are more likely to thrive academically.

CRT-enhanced STEM curricula increase student engagement with content (Hernandez et al., 2013; Lee et al., 2008; Nykiel-Herbert, 2010; Sanford et al., 2020), boost students' school attendance (Bernard, 2004), improve their grade point averages, and encourage the formation of positive racial self-images (Butler-Barnes et al., 2017). Therefore, CRT is critical to the educational success of multilingual students.

Visual Literacy

With abundant visual representations in daily life and, increasingly, in STEM education, a brief discussion of the unique features of visuals is necessary. First, visuals are neither objective nor complete. For instance, photos are confined by the frame, reflecting the photographers' perspectives (Sandweiss, 2007). Similarly, maps are limited in providing a comprehensive view of geographic areas as well as how humans interact with nature (Huffman, 1997). Further, visuals are created in specific sociocultural contexts. Visual elements such as line, color, shape, and symbol are interpreted differently depending on the cultural backgrounds of viewers (Knight et al., 2009).

Given the visuals' subjective, incomplete, and culturally specific nature (Chen, 2019), it is problematic to assume that multilingual students would have no problem making sense of the meaning if visuals were provided. All students must learn visual literacy skills to work effectively with visuals (Avgerinou, 2001). Along the same line, the WIDA (World-Class Instructional Design and Assessment) framework (2020), which designs language development standards for multilingual students, emphasizes the importance of

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using a multimodal approach in the interpretive and expressive communication domains. Such an approach encourages teachers to expand beyond traditional print to include modes of communication such as visuals.

Like traditional literacy, visual literacy can be generally broken down into "reading" and "writing." When "reading" visuals, students view, analyze, interpret, and evaluate visual information. When "writing" visuals, students produce, design, and create information visually. Most importantly, visual thinking and learning skills are essential in constructing meaning from visuals and creating visuals.

Inquiry-Based Learning
Inquiry-based learning (IBL) shifts traditional teaching and learning in the classroom. As a student-centered approach, teachers take the role of facilitators to engage students in conceptual development and phenomenon exploration in STEM. When students engage in IBL, they connect exploration with the natural world to develop an understanding of STEM phenomena. IBL varies from more structured to open-ended, depending on students' experiences and teacher support (Smithenry, 2010; Spronker-Smith et al., 2012). The IBL cycle generally starts with posing questions, problems, or scenarios; through this method, students formulate hypotheses and test them through experiments and/or observations (Pedaste et al., 2012). Through IBL, students follow approaches and practices similar to what scientists do to produce new knowledge in their disciplinary fields (Keselman, 2003).

Recent studies have shown evidence of multilingual students' meaningful and active engagement in the context of authentic STEM activities and practices (Lee & Januszyk, 2021; NASEM, 2018). Multilingual students can learn not only STEM content but also self-reflect on their diverse experiences and cultural resources (MacDonald et al., 2017).

Putting it all Together
The three theoretical perspectives complement each other to frame an integrated approach to STEM teaching and learning with multilingual students. First, CRT foregrounds selecting inclusive visuals that highlight representations of people from marginalized groups. Multilingual students are more likely to continue pursuing future studies and careers in STEM if they see people who look like themselves participate in STEM professions (Bieri Buschor et al., 2014; Ijoma et al., 2022). Moreover, inclusive visuals should reflect diverse experiences to which multilingual students can connect. Priority should be given to visuals demonstrating a topic of student interest or local community concern.

Second, visual literacy expands traditional, text-based literacy to multiple literacies critical to global citizens' competence (Brown, 2022). Visuals help multilingual students break free of language barriers to access the core curriculum, make connections to their prior knowledge, and celebrate diverse perspectives. Visual literacy strategies provide explicit and purposeful support for multilingual students to develop visual literacy and language skills in meaningful STEM content.

Third, utilizing IBL as the primary approach to instruction is aligned with the components of CRT and visual literacy. Student-centered learning with cultural scaffolding sends the message that multilingual students are capable and have the knowledge and experiences to construct meaning (Gay, 2002). Holistic and integrated learning challenges educators and students to make connections across content areas and socio-historical, political, and cultural contexts. Informed by CRT, visual literacy, and IBL, STEM teachers are equipped with pedagogical practices to empower multilingual students to deconstruct visuals and develop visual narratives that communicate learning creatively and critically.

Finally, it is vital to consider the shift of contemporary views on science and language (Lee & Januszyk, 2021) as reflected in the Next Generation Science Standards (NGSS) (NRC, 2013) and the WIDA framework (2020). Specifically, the view on science has changed from *what knowledge is* to *what knowledge does*. Similarly, the view on language has shifted from *what language is* to *what language does*. The WIDA 2020 framework identifies essential language uses to communicate and negotiate ideas across disciplines. In STEM, the most relevant key language uses are the discourse patterns to explain, argue, and inform.

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Implementing the Integrated Approach

The pedagogical implication from the theoretical and changing perspectives of STEM and language is integrating content, language, and visual literacy to support multilingual students' STEM inquiry. Inclusive visuals are viewed as texts that embed rich and culturally responsive STEM content. As students work on their visual literacy skills, there are ample opportunities for multilingual students to use academic language in meaningful contexts. Further, through instructional support such as TALKMOVES (TALKMOVES, 2022) and sentence frames, multilingual students can practice the discipline-specific discourses (i.e., talk, write, and think like STEM professionals) as they explore what they can do with STEM (Aguirre-Muñoz & Pando, 2021). The key multilingual student support strategies are summarized below in Table 1. This table is by no means an exhaustive list of multilingual student support strategies; rather, it is a list of those the authors found to be most appropriate for the context of the paper. These strategies will be elaborated on in detail in the examples below.

Table 1
Multilingual Student Support Strategies

Content/Visual Literacy Strategies	Academic Language and Discourse Strategies
A. Modeling and guided practice to work with visuals through visual thinking routines B. Visual aids C. Graphic organizers D. Multiple modalities (input) E. Translation	A. Repeated use of academic vocabulary in meaningful contexts B. Word banks C. Talk moves/Sentence frames D. Multiple modalities (output) E. Translanguaging

The authors share examples of the integrated approach from the instructional activities developed by participating pre- and in-service teachers in the LOC TPS project. Specifically, the examples fall into four categories. First, inclusive visuals help multilingual students make sense of STEM content and engage in a topic. Second, modified visual aids such as graphic organizers deepen multilingual students' understanding of how concepts are organized and related. Third, with language, visual literacy, and content support, multilingual learners can bridge everyday discourse to the specialized STEM discourse of CER (McNeill & Martin, 2011), namely by developing claims, locating evidence, and constructing reasoning from visually represented data sets. Fourth, with access to visuals and other modes, multilingual learners are empowered to communicate their learning and unleash their creativity to design and problem-solve.

Sense-Making to Engage Multilingual Students

One of the effective strategies for multilingual students is to use visuals to build content understanding and develop academic language (Bicen & Beheshti, 2022; Wright et al., 2015). The following instructional activity example is from a unit designed for a group of middle school students. The school community is in Chicago, and students are familiar with the mid-western urban environment. The teacher intentionally selects visuals that illustrate Chicago across different historical periods (see Figures 2, 3, and 4). Students explore these visual data of Chicago to answer the guiding question, "What changes occur in cities that have increased in population?"

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Figure 2
Chicago 1857 (Palmatary et al., 1857)

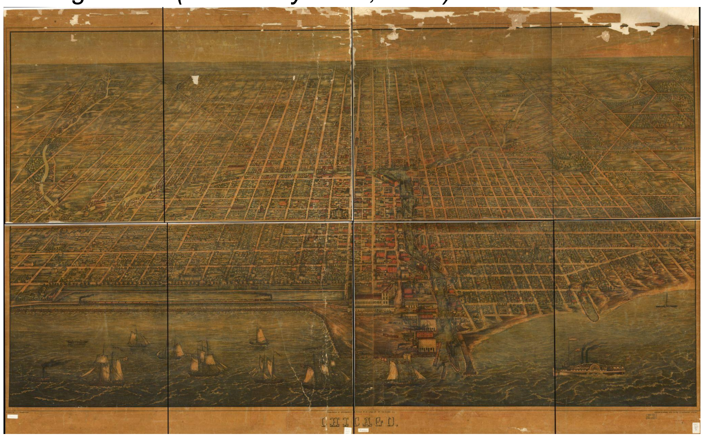

Figure 3
Chicago 1916 (Reincke, 1916)

Figure 4
Chicago 1980-2006 (Highsmith, n.d.)

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This visual literacy activity is guided by the inquiry-based *Notice and Wonder* thinking routine (National Council of Teachers of Mathematics, n.d.). First, students look at the images one by one and record their observations (i.e., what they notice). Multilingual students have access to a word bank where each content word is illustrated by a picture to cue the meaning. They then compare the photos across time, discussing what they think are the changes to Chicago (e.g., size/number of buildings, cars, trees/green space, population, etc.). To support multilingual students to communicate learning and develop academic discourse in English, the teacher prepares sentence frames for them to describe the changing patterns observed in the photos. For instance, one sentence frame is "Compared to …., there are less/more … in …."

The next step is for students to discuss things they might be wondering about in a group (e.g., uniqueness to Chicago, urban vs. rural, actual population changes per photo, etc.). Students have the opportunity to ask clarifying questions and conduct a follow-up investigation. For example, students who wonder if the changes are unique to Chicago or if the conclusions are more generalizable are provided with the option to choose another city of personal importance and explore its changes through the web-based Google timelapse, which provides an interactive visualization of how the Earth's surface has changed over the past few decades. Students conclude that their observations (e.g., buildings, cars, population, greenspace) are consistent across many areas, but changes vary depending on population growth and other factors. By integrating culturally relevant visual data into *the Notice and Wonder* thinking routine, multilingual students connect discipline-specific discourse to compare and explain community issues, informing their decisions as they expand learning beyond the classroom.

Deepening Understanding through Graphic Organizers

Graphic organizers (e.g., KWL charts which include three columns titled What we already **k**now, What we want to **k**now, and What we have **l**earned) are often used to connect students' prior knowledge and new learning. Using graphic organizers can build new learning on students' funds of knowledge and invite students to observe and think about the STEM phenomena they plan to explore. Graphic organizers (e.g., Venn diagrams) also facilitate students' processing of information organization by identifying key categories or providing guiding questions. Visual displays of information can promote students' cognitive processing when learning new information (McCrudden & Rapp, 2017). Teachers can use graphic organizers in one activity or throughout the inquiry cycle to help students deepen their learning. For multilingual students, the significance is that graphic organizers can mitigate students' cognitive load by breaking down the large chunks of information into manageable and organized formats. Moreover, graphic organizers can be adapted by adding students' primary languages to promote the transfer of knowledge across languages.

An example of the effective use of graphic organizers is from a group of pre-service teachers enrolled in the elementary math methods course. The primary source analysis tool, a graphic organizer from the LOC, was used to organize the observation and reasoning of STEM-related content (Library of Congress, n.d.). The top section of the graphic organizer consists of three columns: Observe, Reflect, and Question. As they explore the visual, these three columns guide learners through the See, Think, and Wonder thinking route (Project Zero, 2022). The bottom section of the organizer lists prompts for further investigation and additional notes to answer the questions.

The pre-service teachers were given a primary source–*Remembering the Weather that Day* (see Figure 5), in order to understand and interpret the daily weather conditions. The visual was the record of the weather conditions in New York City on 9/11, including the data on time, temperature, dewpoint, pressure, visibility, wind speed, and conditions. This primary source was a good example to demonstrate to the pre-service teachers how to relate STEM content to students' real life and connect the STEM content to critical cultural and social issues in communities.

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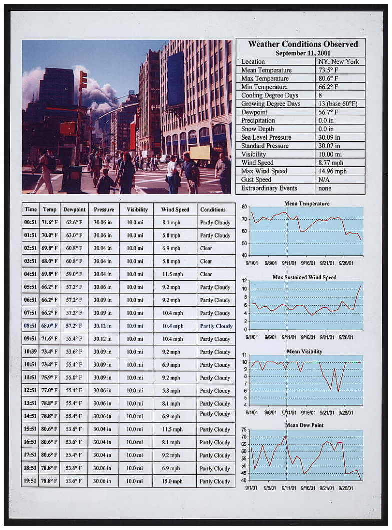
Figure 5

Remember the Weather that Day (Chen, 2001)



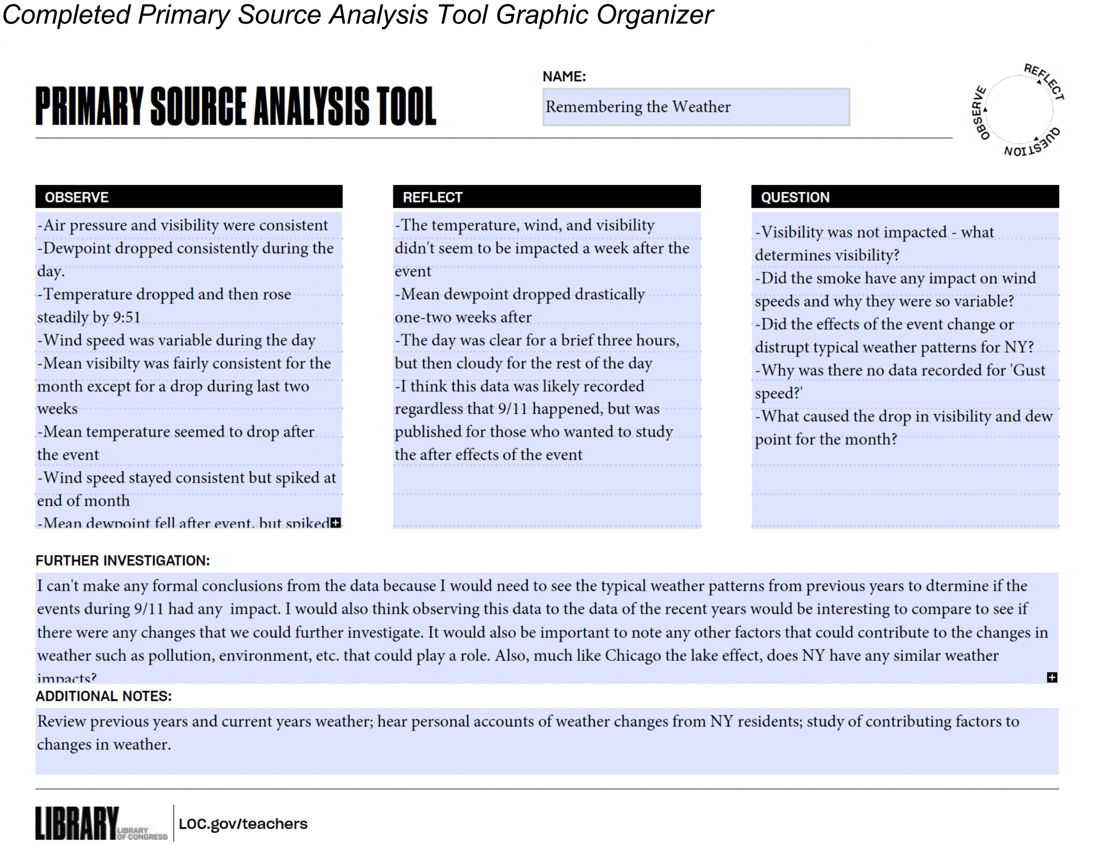
Weather Conditions Observed September 11, 2001	
Location	NY, New York
Mean Temperature	73.5° F
Max Temperature	80.6° F
Min Temperature	66.2° F
Cooling Degree Days	8
Growing Degree Days	13 (base 60°F)
Dewpoint	56.7° F
Precipitation	0.0 in
Snow Depth	0.0 in
Sea Level Pressure	30.09 in
Standard Pressure	30.07 in
Visibility	10.00 mi
Wind Speed	8.77 mph
Max Wind Speed	14.96 mph
Gust Speed	N/A
Extraordinary Events	none

Time	Temp	Dewpoint	Pressure	Visibility	Wind Speed	Conditions
00:51	71.6° F	62.6° F	30.06 in	10.0 mi	8.1 mph	Partly Cloudy
01:51	70.0° F	63.0° F	30.06 in	10.0 mi	5.8 mph	Partly Cloudy
02:51	69.8° F	60.8° F	30.04 in	10.0 mi	6.9 mph	Clear
03:51	68.0° F	60.8° F	30.04 in	10.0 mi	5.8 mph	Clear
04:51	69.8° F	59.0° F	30.04 in	10.0 mi	11.5 mph	Clear
05:51	66.2° F	57.2° F	30.06 in	10.0 mi	9.2 mph	Partly Cloudy
06:51	66.2° F	57.2° F	30.09 in	10.0 mi	9.2 mph	Partly Cloudy
07:51	66.2° F	57.2° F	30.09 in	10.0 mi	10.4 mph	Partly Cloudy
08:51	68.0° F	57.2° F	30.12 in	10.0 mi	10.4 mph	Partly Cloudy
09:51	71.6° F	55.4° F	30.12 in	10.0 mi	10.4 mph	Partly Cloudy
10:39	73.4° F	53.6° F	30.09 in	10.0 mi	9.2 mph	Partly Cloudy
10:51	73.4° F	55.4° F	30.09 in	10.0 mi	6.9 mph	Partly Cloudy
11:51	75.9° F	55.0° F	30.09 in	10.0 mi	9.2 mph	Partly Cloudy
12:51	77.0° F	55.4° F	30.06 in	10.0 mi	5.8 mph	Partly Cloudy
13:51	78.8° F	55.4° F	30.06 in	10.0 mi	8.1 mph	Partly Cloudy
14:51	78.8° F	55.4° F	30.06 in	10.0 mi	6.9 mph	Partly Cloudy
15:51	80.6° F	53.6° F	30.04 in	10.0 mi	11.5 mph	Partly Cloudy
16:51	80.6° F	53.6° F	30.04 in	10.0 mi	8.1 mph	Partly Cloudy
17:51	80.6° F	55.4° F	30.04 in	10.0 mi	9.2 mph	Partly Cloudy
18:51	78.8° F	53.6° F	30.06 in	10.0 mi	6.9 mph	Partly Cloudy
19:51	78.8° F	53.6° F	30.06 in	10.0 mi	15.0 mph	Partly Cloudy

The pre-service teachers completed the graphic organizer to record their observations, reflected upon the primary source to generate and test hypotheses about the source, and raised critical questions for more observations and reflections (see Figure 6).

Figure 6

Completed Primary Source Analysis Tool Graphic Organizer



PRIMARY SOURCE ANALYSIS TOOL

NAME: Remembering the Weather

OBSERVE

-Air pressure and visibility were consistent
-Dewpoint dropped consistently during the day.
-Temperature dropped and then rose steadily by 9:51
-Wind speed was variable during the day
-Mean visibilty was fairly consistent for the month except for a drop during last two weeks
-Mean temperature seemed to drop after the event
-Wind speed stayed consistent but spiked at end of month
-Mean dewpoint fell after event, but spiked

REFLECT

-The temperature, wind, and visibility didn't seem to be impacted a week after the event
-Mean dewpoint dropped drastically one-two weeks after
-The day was clear for a brief three hours, but then cloudy for the rest of the day
-I think this data was likely recorded regardless that 9/11 happened, but was published for those who wanted to study the after effects of the event

QUESTION

-Visibility was not impacted - what determines visibility?
-Did the smoke have any impact on wind speeds and why they were so variable?
-Did the effects of the event change or distrupt typical weather patterns for NY?
-Why was there no data recorded for 'Gust speed?'
-What caused the drop in visibility and dew point for the month?

FURTHER INVESTIGATION:

I can't make any formal conclusions from the data because I would need to see the typical weather patterns from previous years to dtermine if the events during 9/11 had any impact. I would also think observing this data to the data of the recent years would be interesting to compare to see if there were any changes that we could further investigate. It would also be important to note any other factors that could contribute to the changes in weather such as pollution, environment, etc. that could play a role. Also, much like Chicago the lake effect, does NY have any similar weather impacts?

ADDITIONAL NOTES:

Review previous years and current years weather; hear personal accounts of weather changes from NY residents; study of contributing factors to changes in weather.

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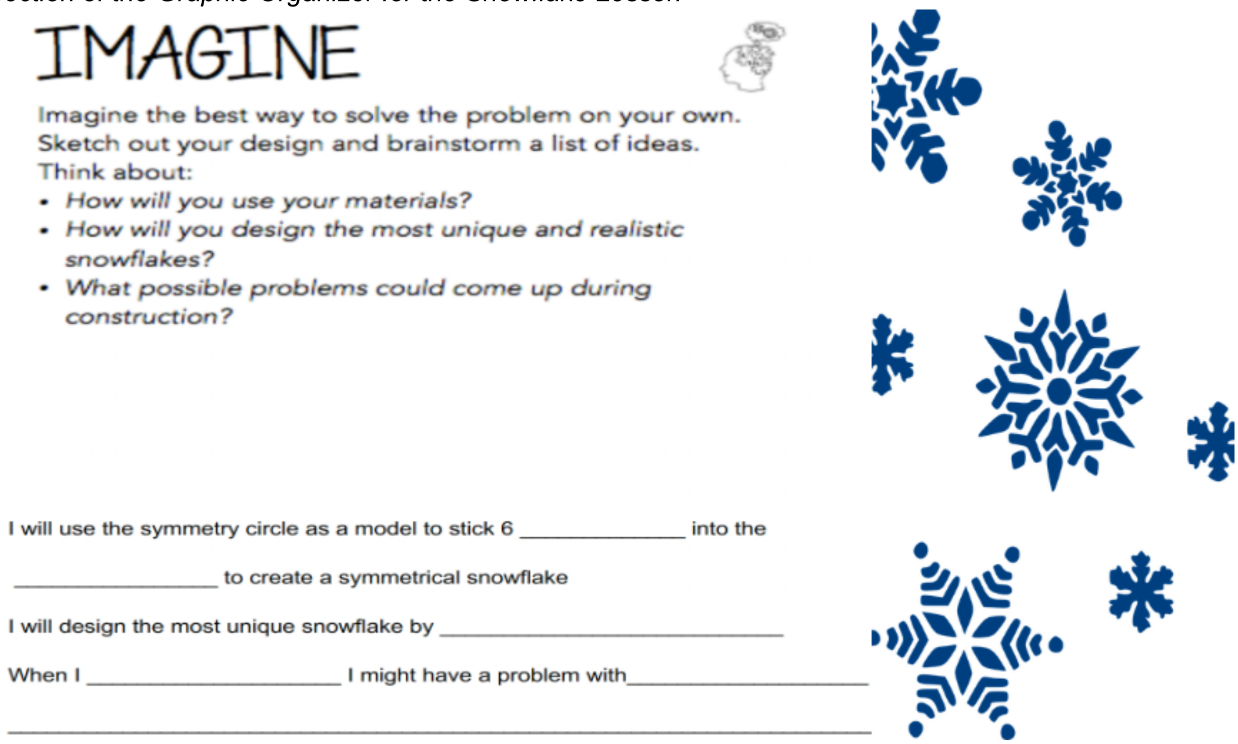
Teachers can adapt and use graphic organizers to facilitate multilingual students' visual thinking and learning in STEM. The adaptation of graphic organizers primarily focuses on two aspects. The first is to support multilingual students' comprehension of a task. For instance, if multilingual students do not understand the meaning of "Further Investigation," they will not be able to generate relevant information to complete the section. One approach teachers can adopt is to use the image of a magnifying glass as a visual aid to explain the meaning of "Further Investigation." The second aspect of the adaptation is to provide scaffolding for multilingual students to practice discipline-specific discourse. In this case, teachers can provide a list of content vocabulary and sentence frames focusing on the language features (e.g., words, phrases, clauses, and types of sentences) to achieve the key language function (e.g., explain, argue, inform) (WIDA Standards Framework, 2020).

The example below illustrates how the pre-service teachers in the project designed and adapted graphic organizers for multilingual students to explore, explain, elaborate, and evaluate their inquiry in STEM lessons. For example, when examining and constructing symmetrical snowflakes, students were given a graphic organizer at each inquiry phase that visually displayed what students were expected to do and how to accomplish the task. Using graphic organizers, students identified the problem, brainstormed a way to solve it, designed a plan, experimented and built their snowflakes, and reflected upon possible improvements. Figure 7 depicts a section of the graphic organizer used in the lesson to facilitate students' thinking while they designed their snowflakes.

Figure 7

Section of the Graphic Organizer for the Snowflake Lesson


IMAGINE

Imagine the best way to solve the problem on your own.
Sketch out your design and brainstorm a list of ideas.
Think about:

- *How will you use your materials?*
- *How will you design the most unique and realistic snowflakes?*
- *What possible problems could come up during construction?*

I will use the symmetry circle as a model to stick 6 ______________ into the

________________ to create a symmetrical snowflake

I will design the most unique snowflake by ____________________________

When I ____________________ I might have a problem with___________________

____

The "imagine" task is further elaborated by three guiding questions and a visual of a thinking brain. To respond to these questions, multilingual students can employ the given sentence frames to collect and record thoughts. This creates an opportunity for multilingual students to practice key vocabulary words, summarize important ideas, and predict possible difficulties when constructing their symmetrical snowflakes.

Additional strategies to support multilingual students include providing a version of the graphic organizer in students' primary language and creating the space for translanguaging (Garcia et al., 2016). Translanguaging means that students can use all their linguistic repertoire while they engage in the discussion of inclusive visuals.

Graphic organizers can be used to develop and enhance multilingual students' knowledge when students are invited to observe and think about STEM phenomena and connect lived experiences to STEM topics. Further, graphic organizers provide guiding questions and organized information for multilingual students, which deepens their understanding of STEM topics and implementation of STEM experiments.

Practicing STEM Disciplinary Discourse–CER

Claim, Evidence, and Reasoning (CER) are the major components that organize the discourse pattern of scientific explanations. Based on the NGSS (2013), K-12 students are expected to construct evidence-based explanations (Buxton & Lee, 2010; NASEM, 2018). The CER discourse pattern is challenging for all students, but for multilingual students, the pattern needs to be explicitly introduced and modeled. It is essential to integrate STEM content and language learning through scientific investigation in order to scaffold CER.

According to the WIDA 2020 Standard 4: Language for Science, multilingual students are expected to achieve a high level of disciplinary discourse. Use the WIDA 2020 Language for Science Standard for 4th and 5th grades as an example: One of the most critical languages uses is "Argue." For this crucial language use, multilingual students are expected to interpret scientific arguments by "comparing **reasoning** and **claims** based on **evidence**." Students are able to construct scientific arguments that "signal logical **relationships** among **reasoning**, relevant **evidence**, data, and/or a model when making a **claim**" (the authors' boldfaced keywords connected to CER). To achieve a high level of disciplinary discourse, multilingual students need continuous support for learning STEM content as well as opportunities to practice the discourse pattern of CER.

In the following example, the 4th and 5th graders work on a unit that explores how architects use shapes to adapt to the local environment. The class consists of multilingual students from different parts of the world -- several Muslim students and recent immigrants from India. The teacher selects photos of well-known buildings around the world. One of them is a photo of the Taj Mahal (see Figure 8), a masterpiece of Muslim art and a symbol of India's rich history. It is also rated as one of the world heritage sites by UNESCO, attracting millions of visitors worldwide each year.

Figure 8

Agra, Taj Mahal (Zürich, 1890-1900)

Students work in small heterogeneous groups to construct collaborative reasoning and problem-solving skills in STEM and real life (STEM discourse, 2017). Further, peers apply the revoicing strategy (Ferris, 2014) demonstrated by their teacher to model how language is used to achieve the purpose of the key language use: Inform. Working in groups, peers can also provide immediate feedback on language use and the CER discourse pattern. That is, they can discuss whether the language used by each other gets

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the point across and serves as a strong piece of evidence or reasoning for the claim. The small group discussion gives multilingual students the opportunity to engage in the CER discourse orally. Such practice helps all students transition more confidently to the writing domain to construct their CER.

To guide thinking in the CER discourse pattern, multilingual students are provided with a *TALKMOVES* handout (Table 3). The left column of the handout provides a guiding question to help students understand what each of the C, E, and R means. The right-hand column includes sample discourse frames to organize the language for each component. Small group discussion allows multilingual students to develop the CER discourse pattern in the listening and speaking domain with appropriate support.

Table 3
Sample Multilingual Student TALKMOVES for CER

TALKMOVES	Discourse Frames
Making a **claim** (What is my conclusion based on the data?)	Architects use …. (shapes) in the building to … … are the shapes used in the building to …
Presenting the **evidence** (What do I notice from the data?)	Based on …, the local environment is … … are shapes I observed in the photo.
Explain the **reasoning** (How do I connect the evidence to the claim?)	… (shapes) are used to build … because …. … (features of shapes) are the best to address … (local environment conditions).

This example illustrates the opportunities multilingual students have to repeatedly use discipline-specific language and discourse through scaffolded visual literacy STEM content. In addition to English, the teacher encourages multilingual students to use their primary language and multimodalities, such as drawing, to contribute to the CER.

Multimodal Communication
Visual literacy is not just deconstructing visuals to learn the content and language. It also involves skills to reconstruct visuals to communicate meaning. While multilingual students may be limited by what they can communicate in English, they can demonstrate evidence of learning if they are supported with multiple modalities.

The example included here shows the initial and revised ecosystem models created by a pre-service teacher in the science methods course. In Figure 9, the teacher identifies the basic elements of the tall grass prairie with detailed drawings and labels. However, the model does not show what categories the elements belong to and how they interact with each other.

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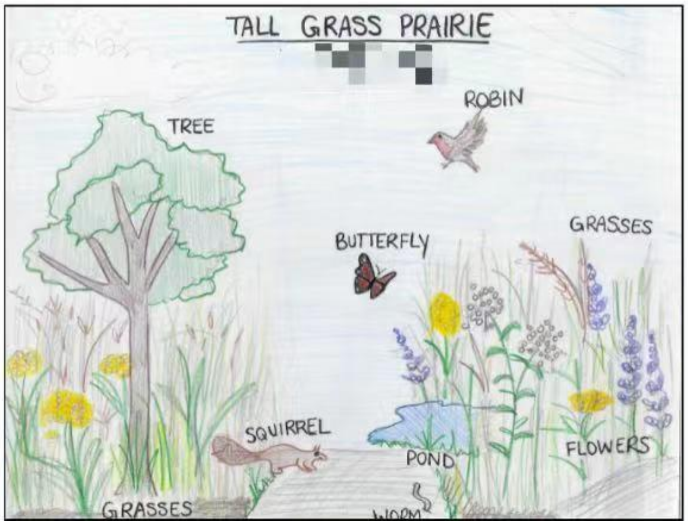
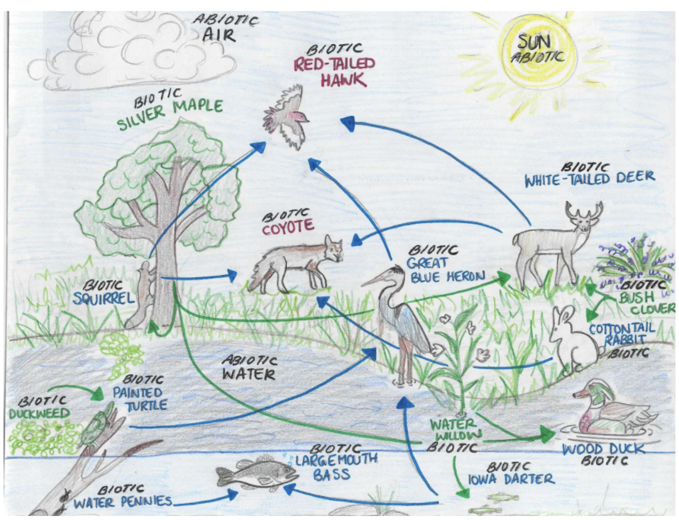
Figure 9
Initial Model of the Ecosystem in Tall Grass Prairie



The initial model is completed as a pre-assessment to establish a baseline for learning. Upon finishing the learning segment, the teacher creates a revised model (see Figure 10). In this model, the teacher not only categorizes the abiotic (i.e., sun, air, and water) versus the biotic (e.g., squirrel and silver maple) elements but also uses arrows to show how energy moves from one to the other elements to form an ecosystem. The comparison of the two models shows strong evidence of content mastery.

Figure 10
Revised Model of the Ecosystem in Tall Grass Prairie



While multilingual students do not necessarily create these drawings, the implication of using visuals instead of print as the primary mode of communication sends a powerful message. Evidence of learning can be in different formats, and educators must shift away from collecting assessment evidence based on English or text only (Gottlieb, 2021). For younger multilingual students, teachers can provide students with classroom materials to create a 3-D model related to a STEM topic. Older multilingual students can leverage primary language, drawing, and/or technology to demonstrate their conceptual understanding of the content as well as critical thinking and problem-solving skills by creating something innovative (Brown, 2022).

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Using inclusive visuals and multilingual student support strategies during the various inquiry phases, teachers can gather a plethora of formative and summative data to assess students' mastery of language features, including the use of vocabulary, phrases, and sentence structure in the context of STEM (NASEM, 2018). Moreover, the data analysis can inform teachers about the next steps in how to model specific language features and evaluate students' responses to the modeling.

Conclusion

This paper proposes an innovative approach to integrate content, language, and visual literacy to promote engagement and investment in multilingual students in STEM education. This integrated approach is built on three theoretical perspectives: Culturally responsive teaching, visual literacy, and inquiry-based learning. These theoretical perspectives guide teachers in several ways as they implement the integrated approach in STEM teaching and learning. First, it is important to select inclusive visuals that connect to multilingual students' lived experiences and funds of knowledge. Second, using inclusive visuals as texts in the inquiry cycle provides multilingual students opportunities to engage in authentic STEM practices, practice disciplinary language and discourse in meaningful contexts, and progressively enhance their visual literacy skills. Third and last, as they are scaffolded with a variety of adapted content, language, and visual literacy strategies, multilingual students, in collaboration with peers and teachers, move to the center stage in STEM reasoning and problem-solving.

As the education landscape becomes more multimodal, the demand for visual literacy is high for all students. Without visual literacy skills, it is challenging to view and process information with a critical mind. The authors present theoretical perspectives in this paper to guide teachers in selecting inclusive visuals and designing inquiry-based visual literacy activities, which promote multilingual students' disciplinary language, discourse, and content learning in STEM. Shared examples in the paper can inspire STEM educators to implement appropriate strategies to create culturally responsive teaching and learning opportunities. This approach will empower all students, especially multilingual students, to pursue advanced STEM research and add new perspectives that are traditionally excluded from STEM.

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Acronyms Used in the Paper

Culturally Responsive Teaching–CRT
Library of Congress–LOC
Inquiry-based Learning–IBL
Next Generation Science Standards–NGSS
Science, Technology, Engineering, and Mathematics–STEM
Visual Literacy–VL
World-Class Instructional Design and Assessment–WIDA

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