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# One teacher's approach to supporting multilingual learners through community-connected engineering design (fundamental)

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# One Teacher's Approach to Supporting Multilingual Learners Through Community-Connected Engineering Design (Fundamental)

## 1. Introduction

The NGSS highlights the importance of connecting engineering to place and context to support the learning and engagement of all students in STEM [1]. A Culturally Relevant Engineering Design (CRED) Framework [2] that allows students to solve meaningful problems through engineering in their local community can increase relevance and deepen science and engineering understandings for all students. Engineering design challenges that relate to students' daily lives hold the potential for eliciting students' funds of knowledge, or the "historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" [3]. Wilson-Lopez & Acosta-Feliz [4] found that connecting engineering tasks to students' communities also offered opportunities for teachers to engage in translanguaging pedagogies to support multilingual learners (MLs).

A review of the literature shows that studies on engineering education for MLs – also referred as English learners [ELs] or emergent bilinguals/multilinguals [EB/EM]) – remain relatively limited. However, existing research highlights the importance of engaging MLs in engineering education to support both their language development and their engineering learning. For example, Cunningham et al. [5] identified significant affordances in teaching engineering to MLs. They emphasized that engineering education is inherently hands-on, collaborative, and provides authentic opportunities for MLs to develop their language skills within meaningful learning environments. Additionally, engineering education fosters a culture of risk-taking among students, and this culture of embracing failure and risk-taking may help students become more comfortable with linguistic risks. Furthermore, engineering tasks often necessitate multimodal communication such as writing, drawing, and gesturing, and "displaying information multimodally supports [MLs'] receptive language" (p. 267). Studies have also proposed effective ways of teaching engineering to MLs. For example, Lee et al. [6] proposed that MLs benefit from engaging with multiple modalities (e.g., visuals, diagrams, and linguistic models). Garlick and Wilson-Lopez [7] recommended using contextualized, relevant, and culturally responsive engineering challenges.

Building on these insights, the present study aims to contribute to the literature by exploring one teacher's experience as a teacher of MLs within the context of culturally relevant engineering education in her classroom. The purpose of this study was to understand how these community and localized connections and culturally responsive approaches can be infused throughout all stages of the engineering design process to support all learners. This case study is part of a larger NSF-funded project focused on supporting rural elementary teachers' classroom implementation of culturally relevant engineering design. This holistic case study [8] focuses on a single teacher, Serena, as she implements a community-connected engineering design task using the CRED Framework with her class of 4th grade MLs. We sought to answer the following research questions:

1. How does Serena embed community throughout all phases of the Culturally Relevant Engineering Design (CRED) Framework?
2. How does Serena support multilingual learners (MLs) as she teaches engineering?

## 2. Background

### 2.1. Engineering Design Context in Elementary Education

Internationally, there is an increasing call for greater integration of the STEM domains in PK-12 classrooms, with particular attention on the incorporation of engineering concepts and practices into science curricula [9]. While the inclusion of engineering content and standards has increased in STEM classrooms since the adoption of the Next Generation Science Standards [1], greater understanding is needed among teachers, specifically at the elementary level, about the rationale and intent of including engineering education, as highlighted by the National Research Council [10], [11] Engineering education not only allows students to meaningfully apply science concepts and content to relevant real-world problems, thereby increasing learning and engagement across disciplines, but also supports students' development of the skills and dispositions they will need as literate citizens to address societal and global challenges [1], [12], [13].

Despite this increased interest in implementing engineering instruction across pre-college classrooms, research is still needed to better understand the scope of best practices and conditions for effective engineering education within elementary classrooms. Literature suggests that intentionally framing engineering lessons within the Engineering Design Process (EDP) allows elementary students to engage in the processes of design and redesign, with authentic applications of disciplinary knowledge [9], [10]. However, studies also show that elementary teachers may be less likely to devote equal time and scaffolding to each stage of the EDP, often limiting the problem scoping and information gathering stages and spending more time on the planning and design phases, likely due in part to elementary teachers' lack of familiarity with the EDP [14], [15]. Without adequate time for students to develop their understanding of the problem, engineering tasks may become decontextualized and lack relevance for students. Further, centering student discourse, argumentation, inquiry, and use of epistemic tools throughout each stage of the EDP can support elementary students' knowledge construction and application of engineering practices [13], [15], yet professional development, resources, and materials specific to engineering instruction are needed for elementary teachers to feel equipped to integrate it effectively into their STEM classrooms [10].

### 2.2. Community-based Engineering

Engineering has the potential to connect classroom instruction with community-based ways of knowing [16], and *The Framework for P12 Engineering Learning* [17] highlights the need to connect classroom engineering lessons to students' communities. The engineering problems that children are presented with must be accessible [18]; thus, centering the problem around children's lived experiences can ensure they understand the scope of the problem. Dorie et al. [19] found that when presented with a generic engineering task (e.g., building a tower), young children would develop their own meaningful context situated within their personal experiences (e.g., an apartment building). English and King [20] noted that the addition of context could be considered foundational to engineering design tasks and offers the opportunity for problem scoping connected to how a design might impact a community. Students often devote inadequate time to problem scoping [21], [22] and while problem scoping is important, it should be embedded within the larger purpose of the activity [23] allowing students the opportunity to define the relevance of problems within their local communities, interview community members, and present their solutions to community stakeholders [24].

Educators who incorporate funds of knowledge into their pedagogical practices recognize community knowledge as an asset in supporting all students. Yosso [25] described community cultural wealth as an a collection of cultural knowledge, skills, abilities, and connections held by groups that frequently remain unrecognized and unappreciated, while deficit thinking suggests that these students and their families are to blame for low academic achievement because: (a) they begin school lacking the typical cultural knowledge and skills, and (b) their parents do not prioritize or support their education. Rural students and communities are often portrayed through deficit lenses, despite the multiple assets afforded within these spaces, including access to science and engineering through activities such as agriculture and proximity to nature [26]. Avery [27] developed the term *local rural knowledge* to describe the funds of knowledge rural children develop while interacting with their families and environments. Specific to STEM education in rural areas, NASEM [26] reports that place-based teaching approaches that leverage funds of knowledge, and local rural knowledge specifically, can enhance students' learning of STEM. Despite the reported importance of pedagogies that connect classroom and community, according to Evans [28], "teachers continue to report that the most significant challenge encountered when entering the profession is the establishment of relationships with families and communities" (p. 123). These relationships form the basis for enacting place-based pedagogies centered around funds of knowledge and community cultural wealth.

## 3. Conceptual/Theoretical Framework

To frame the current study, we focused on culturally relevant engineering instruction, drawing from the work on humanizing pedagogies, the eight competencies for culturally responsive pedagogy, and the Culturally Relevant Engineering Design (CRED) Framework.

### 3.1. Humanizing Pedagogies

Gloria Ladson-Billings and Geneva Gay, leading authorities on humanizing pedagogy, have for many years encouraged educators to collaborate with students and their families to promote what Ladson-Billings [29] described as critical engagement with the world. Ladson-Billings' culturally relevant pedagogy and Gay's culturally responsive teaching frameworks provide essential guidance for preparing teachers to meet the needs of all student populations, as both scholars, despite their distinct paths, underscore the importance of humanizing practices that encourage full engagement between teachers and students in the educational process.

Ladson-Billings [29], [30] argued that knowledge is dynamic and shaped through collaboration, emphasizing that teachers should recognize the perspectives of all students in their practice. By intentionally modifying their approaches, educators can create equitable experiences for all students. This process starts with acknowledging students' existing knowledge and emphasizes the importance of family and community language and culture. By adopting a culturally responsive model of family engagement, teachers can help students foster connections with their peers and cultivate a sense of community among learners, ultimately enhancing their cultural awareness.

Gay [31] contributed to this discussion by asserting that culturally responsive teaching helps students understand that there is no single, absolute truth. When students see their identities reflected in the curriculum, they become equal partners in the educational system. Teachers who actively engage with and appreciate their students' cultural heritages can help them reach their fullest potential. These impactful teaching experiences arise when educators intentionally shift their focus to acknowledge the complete identity of the student. Gay [31] suggested that teacher engagement involves a commitment to both deconstructing and reconstructing one's understanding of self, necessitating reflection and introspection.

Within the framework of care, theory represents a distinct aspect of cultural practices that emphasizes the importance of supporting all students. Culturally responsive caring [31] focuses on the needs of all students. The outcomes of such an approach aim to enhance competence, agency, autonomy, efficacy, and empowerment for all students in educational settings and beyond. Culturally responsive practices also recognize the significance of the cultural heritage of various ethnic groups, viewing these influences as pivotal in shaping students' dispositions, attitudes, and learning methods, while also considering them as essential content for the formal curriculum. This student-centered teaching approach promotes an environment where students can flourish. Educators take on the roles of advocates and mentors, showing deep concern for the emotional, social, and academic well-being of all students, with a particular emphasis on supporting all students.

Culturally responsive teaching recognizes the importance of the cultural heritage of various ethnic groups, acknowledging how these legacies influence students' attitudes, learning styles, and should be included in the formal curriculum across all subjects. This teaching approach is based on the premise that a positive self-concept, pride in one's ethnic identity, and improved academic performance are interconnected. Educators must also address their own cultural gaps to effectively support their students and communities. By collaborating with students, families, and communities, teachers can significantly transform pedagogical practices toward creating a more equitable and democratic society. Culturally responsive teaching is rooted in the commitment of dedicated professionals to empower their students.

Classroom environments transform into spaces of promise and potential by emphasizing each student's unique strengths. The work of both Ladson-Billings and Gay illustrates that these cultural practices prioritize recognizing the humanity of all children. Consequently, such pedagogies are seen as an alternative to the deficit schooling model that persistently dehumanizes students of color. These humanizing pedagogies have influenced the development of additional frameworks, including the Eight Competencies for Culturally and Linguistically Responsive Teaching and the Culturally Relevant Engineering Design (CRED) Framework, both described in greater detail below.

### 3.2. Eight Competencies for Culturally and Linguistically Responsive Teaching

Drawing on research in culturally relevant, responsive, and sustaining pedagogies, Muñiz [32] identified eight key competencies for culturally responsive teaching across grade levels and disciplines (see Figure 1). These include engaging in self-reflection to recognize and address how personal values influence teaching (Competency 1) and understanding how social markers shape educational opportunities (Competency 2). Educators are encouraged to design lessons that connect academic concepts to students' cultural experiences (Competency 3) and help students see the relevance of their learning to their lives, families, and communities (Competency 4). They also emphasized that culturally responsive educators possess a view that all students are capable of academic success (Competency 5) and promote a learning environment that respects differences (e.g., social, cultural, and linguistic differences) (Competency 6). Culturally responsive educators need to see themselves as members of the community and continually seek opportunities to collaborate with families and the local community (Competency 7) and communicate in linguistically and culturally responsive ways by advocating for translation services and resources in various languages (Competency 8).

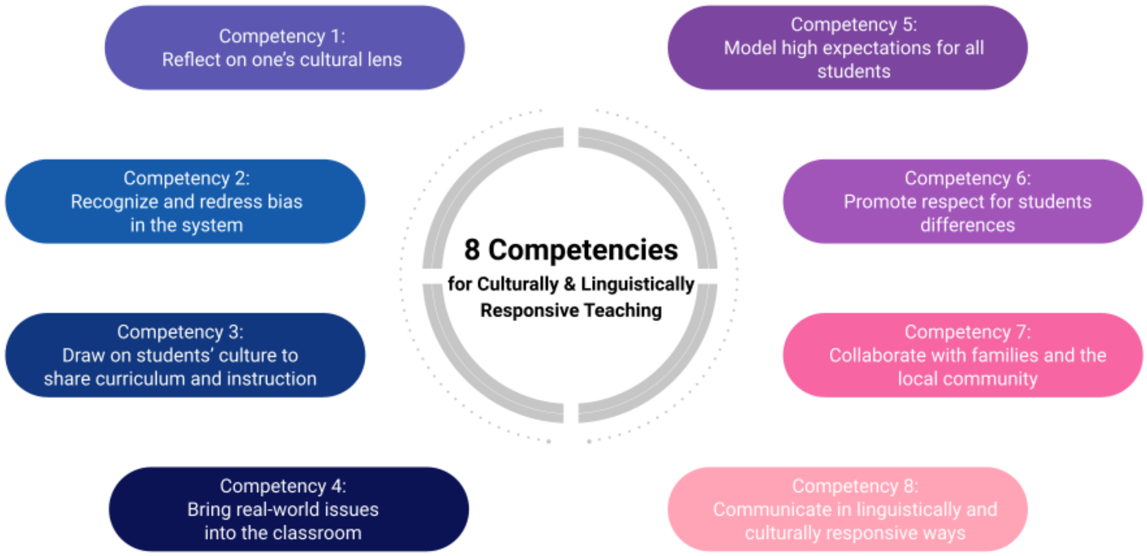


Figure 1. Eight Competencies That Culturally and Linguistically Responsive Educators Possess

### 3.3. Culturally Relevant Engineering Design Framework

To situate the EDP within culturally relevant pedagogy and culturally responsive practice, we use a Culturally Relevant Engineering Design (CRED) Framework [2] to frame engineering education and instruction (see Figure 2). The CRED was developed to explicitly connect each stage of the EDP to community, culture, and place. Adapted from Guerra et al.'s [33] engineering design process, the CRED Framework describes how each stage (Identify, Describe, Generate, Create, Finalize) embeds community-situated engineering needs and the instructional moves to ensure it is situated within a culturally relevant, responsive, and humanizing framework [29], [31]. For example, the *identify phase*, in which the teacher and students work together to define community wants and needs based on their lived experiences and interactions with community members, can embed the tenets of student empowerment and community-based learning and problem-solving. The *describe phase*, in which students learn more about that issue's historical context and impact on community values, provides students with the opportunity to identify the community's desired outcomes. Throughout the *generate* and *create stages* of the CRED, in which students brainstorm and create solutions, students are able to connect solutions specifically to community context and values while engaging in interdisciplinary and multimodal learning approaches. The *finalize stage*, in which students share their final designs within their community, allows students to engage with community members, justify their design solutions within the context of their community, and even take part in subsequent action steps.

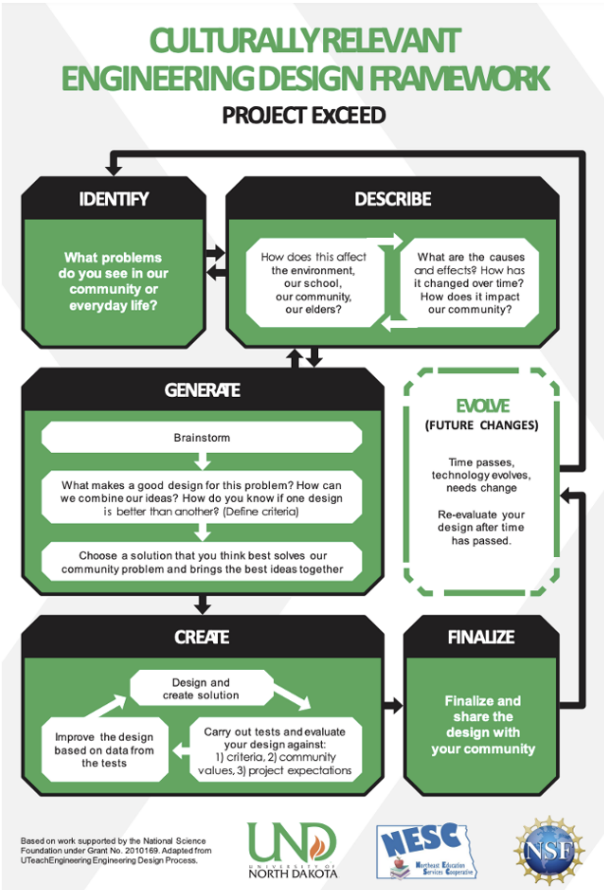


Figure 2. Culturally Relevant Engineering Design (CRED) Framework [2]

**4. Methods**

The humanizing pedagogies found within the Eight Competencies for Culturally and Linguistically Responsive Teaching and the Culturally Relevant Engineering Design (CRED) Framework guided our PL implementation as well as the ways we approached data analysis, as described below.

**4.1. Study Context**

This holistic case study [8] focuses on Serena, a 4th grade teacher who participated in a year-long engineering-focused professional learning (PL) program, during which she was introduced to the CRED Framework and strategies for connecting classroom engineering instruction to her local context. The PL was advertised widely through university and state departments of education listservs and all interested persons who met the grant criteria (currently teaching 3rd through 5th grade in a rural school within the states covered by the grant) were invited to participate. All project recruitment, activities, and data analysis followed the requirements of the governing ethics review board. The PL began with a 5-day-long intensive online summer session containing both synchronous and asynchronous activities designed to introduce teachers to NGSS aligned science and engineering instruction. Following the summer PL, Serena participated in four additional online engineering-focused PL sessions and volunteered to join an engineering learning community (ELC) with other rural elementary teachers to further support the development and implementation of a community connected engineering lesson using the CRED Framework. Serena was the only ELC member whose students were predominantly multilingual learners and was thus chosen as the focus of this case study. See [2], for a detailed description of the year-long PL program Serena participated in. Using the CRED Framework as a guide, Serena designed culturally relevant engineering tasks by first examining her required content within the context of state standards to identify appropriate placement of engineering design tasks in their curricula. She then considered issues related to extreme weather that were relevant to her school community to identify authentic areas of need that students could explore through engineering.

### 4.2. Participant

Serena has 8 years of experience teaching 4th grade in a rural K-8 school in the Western US. The county in which the school resides covers over 8,000 square miles that extend across mountain and desert landscapes, and the economy relies heavily on agriculture. The topography of the county contributes to severe air pollution, and unhealthy air plagues the county many days each year.

Serena identifies as a Hispanic woman, is fluent in both Spanish and English, and describes her students as emerging English language learners. Serena’s 4th grade class has 17 students; 100% are Hispanic with 14 being classified as English Learners, 2 as Limited Fluent English Proficiency, and 1 as English Only.

### 4.3. Data Sources

Serena developed an engineering design task aligned with the CRED Framework and video-recorded her classroom implementation. The design task was taught over the course of 7 sessions, lasting a total of 3.5 hours. After teaching the design task, Serena participated in a 20-minute-long semi-structured interview during which she described her community and classroom contexts. This interview data was used to provide a rich description of Serena and her classroom environment but was not analyzed for use in supporting the classroom video coding due to the purpose of the interview. Thus, data sources for the case study included Serena's lesson plan and classroom video footage.

### 4.4. Data Analysis

We used a multileveled coding approach inspired by the COPED [34]. First, we coded all data based on the CRED Framework. To do this we went through the lesson plan and video footage coding each segment with the stage of the CRED it was aligned with. Next, we went through the data associated with each stage of the CRED and further coded the segments for specific moments when Serena’s instruction included connections to the local community. Further, given the multilingual context of Serena’s classroom, we wanted to place additional emphasis on how she employed linguistically responsive practices to support the MLs in her classroom. Thus, we engaged in an additional round of coding to identify instances of the eight competencies described by Muñiz [32].

During each of the above rounds of coding, we (the authors) first met to discuss the codes to be applied (i.e., CRED stages, community connections, eight competencies) to develop shared definitions of what constituted each code. Then, we individually reviewed the data, recorded analytic memos [35], and coded the data, after which we came together to engage in a collaborative discussion session. For the initial round of coding, our discussion session was used to reach consensus around which video clips corresponded with each stage of the CRED. For the next discussion sessions, we talked about the particular instances we each independently coded as community connections, noting the associated instructional strategies Serena was using during each of those instances. During our initial discussion on the eight competencies, we further refined our shared understanding of what constituted examples of each of the competencies before going back to the data again for another round of coding. During the next session, we shared the instances we coded for the competencies and ensured consensus on how we had applied the coding.

After engaging in the multiple rounds of shared discussion on the coding, we met again to engage in a code mapping discussion [35], during which we linked the CRED stages of the lesson with the instances we had agreed upon for the eight competencies and community connections. Based on our resulting code maps, we developed themes that represented the data. Finally, we engaged in a codeweaving session [35] to “interpret how the individual components of the study weave together” (p. 248) and create a narrative describing the interaction between the major themes.

### 4.5. Instructional Sequence Overview

**Identify (Session 1 & 2):** Session one began with Serena asking the students about what comes to mind when they think about extreme weather. As students shared their ideas, Serena listed them on the board. Serena then asked students to think of examples of extreme weather in small groups and discuss how each example affects people. Following time in their small groups, Serena facilitated a whole class discussion and asked students how examples of extreme weather impacted people in their community. Students proceeded by watching a video on how air pollution affects respiratory health as well as a local weather news video and filled out a graphic organizer with their ‘notices and wonders’ at the conclusion of session one. In session two, Serena facilitated a class discussion about what the PurpleAir sensor does at their school. In this discussion, the students shared ideas about what the air quality scores tell them about the air quality in their area. Serena also showed students an air quality map of the region; discussed the air quality in their area further; and had students brainstorm possible reasons for their poor air quality to help them make connections to local almond farms that contribute to the poor air quality in their community.

**Describe (Session 3 & 4):** Serena focused session three on the causes and effects of poor air quality in her students' local community. First, Serena asked students about the effects of poor air quality in their community. Then she passed out a thinking map (see Figure 3) and asked students to watch a video about air pollution. Together, the teacher and students filled out the thinking map about the causes of air pollution; four types of air pollutants; the health effects of toxic pollutants; and possible solutions to combat air pollution. At the conclusion of session three, Serena and her students read an article about Particulate Matter 2.5 (PM2.5) that is known to cause several health problems. In session four, students were asked to summarize the article they had read. Next, Serena showed the students a video on PM2.5 and had them record their 'notices'. Following this, students worked in pairs to create a poster on PM2.5 that outlined a definition or description of PM2.5, a drawing, and PM2.5's negative health effects.

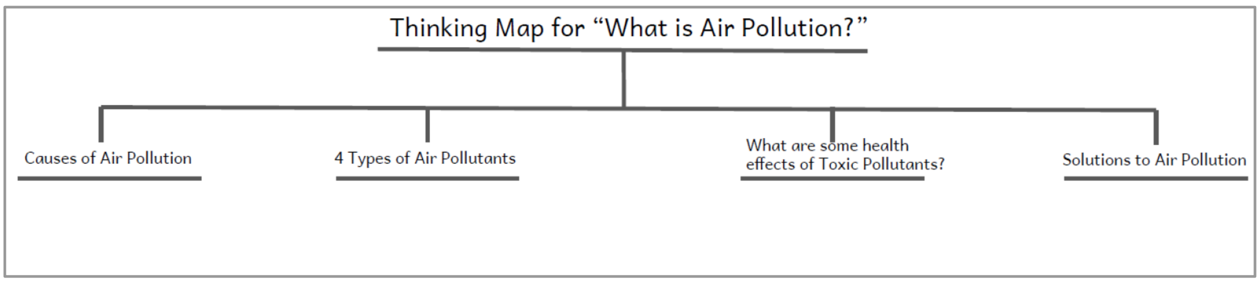


Figure 3. Thinking map

**Generate (Session 5):** Session five served to more formally introduce students to the CRED process. Serena provided students with another graphic organizer and had students begin to identify problems in their area that were related to the poor air quality. After identifying the problem of poor air quality (due to almond farming) in their local community, students were given time to brainstorm possible solutions to help improve their community's overall air quality. Following this, students were given time to sketch their solution in their engineering design graphic organizer. Serena then had students share their design solutions in small groups and grouped students together based on who had similar design solutions. To conclude this session, students collaborated in their small groups and came up with a final design that they sketched in their graphic organizer.

**Create (Session 6):** In session six, students were provided with time to think about the materials that they would need to construct a prototype of their small group's final design. Serena created a classroom pool of materials that contained items students had brought from home as well as items she had collected. Serena played a game with the entire class to distribute the materials to each group, helping to ensure that all groups had access to the supplies they needed even if they were unable to bring items from home. The game reviewed major concepts Serena had covered in prior sessions (e.g., air quality index; PM2.5). Then students had 10 minutes to construct their small group's final design.

**Finalize (Session 7):** To begin session seven, Serena provided students with a handout and had them write down the name of their small group's prototype, its function, and how it would help their community with the air quality problem. Following this, Serena gave each small group a few minutes to present their small group's design and describe its features, functions, and how it would help improve the local air quality in their community. After each small group presented their design, the rest of the students were provided with an opportunity to give each group feedback on how they could improve their designs. To conclude this session, each small group identified at least one way they could improve upon their design and addressed what went well and what did not during the CRED process.

## 5. Findings

Table 1 shows where Serena implemented the competencies for culturally and linguistically responsive teaching within each stage of the CRED Framework.

Table 1. Competencies Present in Each CRED Stage

<table>
<tr><th>CRED Stage</th><th>Session</th><th>Comp 1</th><th>Comp 2</th><th>Comp 3</th><th>Comp 4</th><th>Comp 5</th><th>Comp 6</th><th>Comp 7</th><th>Comp 8</th></tr>
<tr><td rowspan="2">Identify</td><td>1</td><td></td><td></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td></tr>
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<tr><td rowspan="2">Describe</td><td>3</td><td></td><td></td><td></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td></td><td style="background:#ccc"></td><td style="background:#ccc"></td></tr>
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<tr><td>Create</td><td>6</td><td></td><td></td><td></td><td></td><td style="background:#ccc"></td><td></td><td></td><td></td></tr>
<tr><td>Finalize</td><td>7</td><td></td><td></td><td></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td><td style="background:#ccc"></td></tr>
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### 5.1. Community Connections

Lesson segments coded as competency 4 and competency 7 were combined into the theme of *community connections* (see Figure 4).

Throughout the entirety of the instructional sequence, Serena made explicit connections to the local community by situating the activities within the local context and connecting back to student's wonders about local air quality, involving students in researching about their local

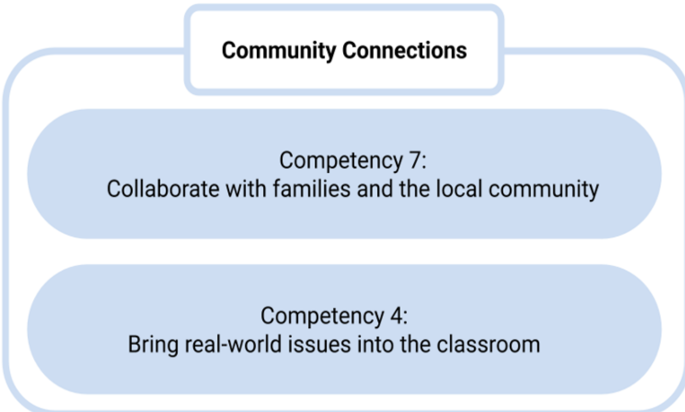


Figure 4. Competencies aligned with Community Connections theme.

context and connecting to community members to further describe the problem and its impact. She began during the Identify stage by asking students to identify examples from their extreme weather list that affect them locally. She facilitated a classroom discussion to elicit students' thinking on the topic. For example, when one student mentioned a tornado, Serena asked a series of questions to identify that the student was referring to a dust storm (they do not experience tornadoes locally); the dust storm would eventually be brought up again by another student when talking about the air quality at the school.

> Serena: "Is there anything else that affects us? Sometimes we can't go outside to PE, not because it's raining, but there's other reasons that we cannot go outside?" [entertains a few student's answers]
> Student: "A dust storm can get you sick because it's all around you because there's those little tractors that kick up the dust."
> Serena: "Okay, good. What do we have all around us?"
> Many students respond "dirt, dust"
> Serena: "What do we have back here [points out one classroom window]"
> Students: "almonds"
> Serena: "What do we have over here [points a different direction]"
> Students: "almonds"

After students identified the location of the surrounding almond orchards, Serena connected their knowledge of the dust from almond harvesting and processing with the local air quality, the problem central to the engineering lesson.

To further engage students in researching the problem, Serena had students interview different community members, watch local news footage, and analyze data from the school's air quality sensor throughout the Identify and Describe stages. As part of the Identify stage, students interviewed the school nurse who shared data on the number of students at the school who had respiratory issues and strategies for avoiding respiratory issues on bad air quality days, such as not going outside when the air quality was bad. Later, during the Describe stage, the bus driver was interviewed about practices to reduce air pollution such as shutting the bus engines off rather than idling them while waiting to pick up students.

During the Identify stage, Serena introduced students to the school's PurpleAir sensor and the students began checking the air quality data every day. She referred to the sensor data multiple times throughout the sessions, providing opportunities for students to make observations and inferences about the data and connect it to their personal experiences. For example, when Serena projected the live PurpleAir data for the region onto the board, students identified the air quality indexes in different locations near their community and began to infer what might be leading to those air quality values. For example, they activated their knowledge about local industries such as factories, airports, and racetracks, as well as knowledge of a wildfire burning near one of the towns with a poor air quality index value.

To finish the Describe stage, Serena had students create posters recapping all the evidence they had gathered through their research, including watching two local news videos, reading a science content article, interviewing two community members, and data collected from the PurpleAir sensor. The videos from the local news station identified the region as having the worst air quality in the nation, as well as how the local topography permits poor air quality. Near the end of the Describe stage, as Serena was asking students to recall all the research they had completed the last few days to understand the problem, she simultaneously checked for students' understanding of some of the underlying factors contributing to the problem.

> Serena: "What type of landform do we live in?"
> Students: "Valley"
> Serena: "So, what happens because we live in the valley?"
> Student: "It [smoke, bad air] can't go anywhere cuz its like stuck in the middle"
> Serena: "Yes, it can't go anywhere in our valley. It is like trapped."
> Student: "It is like a pot."
> Serena: "Yes, you're referring to the video that said we are pretty much like a pot with a lid on top."

As Serena then moved students into the Generate stage, she began by contextualizing the process of generating solutions by connecting back to students' direct experience with the air quality the day prior, asking students to predict what the air quality index value was based on their respiratory symptoms. She also described her own asthma symptoms, saying, "I predict the air quality was red or orange yesterday. Who else has asthma? How did you feel yesterday? It definitely did affect us that have some respiratory issues."

After reviewing their local air quality issues and causes and reviewing the stages of the engineering design process, Serena then had students produce as many different ideas as they could to solve the problems and gave them time to discuss and sketch their ideas with each other. As observed in the Identify and Describe stages, Serena continued to reframe and refocus students on the community connections and relevance their potential solutions had in relation to the problem, asking questions such as, "How does this affect us locally?' and "Is there anything that already exists in our community to solve this problem?" She also asked students to directly connect their solutions to the actual community causes, with students explaining directly how their solution would address air quality issues caused by the almond factory, highway traffic, and the dog food factory.

As students were brainstorming, Serena circulated the room and prompted students to generate as many ideas as possible, guiding students' thinking with open-ended questions and probes. In this manner, Serena provided students the opportunity to continue to ground their ideas for solutions within existing community values, opportunities, and assets yet also gave space for students to be creative and to think outside the box with their ideas. In one instance, a student suggested a cologne factory as a possible solution to the air quality problem. Rather than dismiss the idea, Serena asked further questions to guide the student to explain his thinking further.

> Serena: "Would that be good for the air?"
>
> Student: "You know, like Febreeze."
>
> Serena: "Is Febreeze good for the air? I'm not saying that is a bad idea, maybe we could go somewhere with it. Are you thinking about spraying something in the air? Is that going to make the air better? Is that what is in your brain?"

Through this line of questioning, Serena guided the student to develop his idea further, and they then included it on their class list of potential solutions.

Once students had generated and shared their extensive lists of possible solutions to the air quality problem in their area, Serena gave students the opportunity to select and prototype one of their design solutions. Prior to beginning their construction, she provided students time to talk with their partner for this stage of the activity and discuss their approach to designing and building their solutions, prompting, "I'm going to give you two minutes of thinking time, so you can talk to your partner or your group about other supplies you would need." Throughout this time, Serena reminded students to use full sentences and to continue to explain how their solution would solve the issue in their community.

Students then moved into the Create stage, working in partners to build their solutions. In this way, students continued to connect to their community and their own lives by considering the design and material choice and by the collaborative nature of their construction process. Throughout the Create stage, Serena continued to circulate and prompt students with open-ended questions, with this lesson being primarily student-driven and hands-on.

During the sharing time as part of the Finalize stage, Serena asked students to identify and name their prototype, explain its function, and she continued once again to prompt students to explain how their solution was designed to solve the problem in their community, with such questions as, "How will this help our community?" and "Based on what we learned in our community about air pollution, how will this help?" She also continued to refocus them back to the research they had done on their community's characteristics and geography. For example, for one group that had designed a face mask, Serena asked, "Why did you decide to do a mask, based on what you know about air pollution in our community? How do we know it's bad air? There is a lot of fog, and there is a lot of dirt. But why? What are we surrounded by?"

Several groups of students designed electric vehicles, with their rationale directly connecting to the interview they had done with the bus driver and prior class conversations about air pollution from traffic.

> Serena: "Why did you guys decide to do an electric bus?...So they are trying to save the amount of buses, so you're saying this one bus will bring the whole school?"
> Student: "It could."
> Serena: "How will this [electric car] help our community with our air pollution problem?"

Serena also reinforced students' explanations of the importance of electric vehicles in their community by saying, "And they said it is going to help our community because it won't be another gas vehicle letting out emissions." Serena's use of questioning, prompting, class discussion, and continuous grounding in students' lived experiences provided community connection and relevance throughout each stage of students' engagement in the CRED.

### 5.2. Culturally Responsive Learning Supports

Lesson segments coded under competency 3 and competency 8 were included under the theme *culturally responsive learning supports* (see Figure 5).

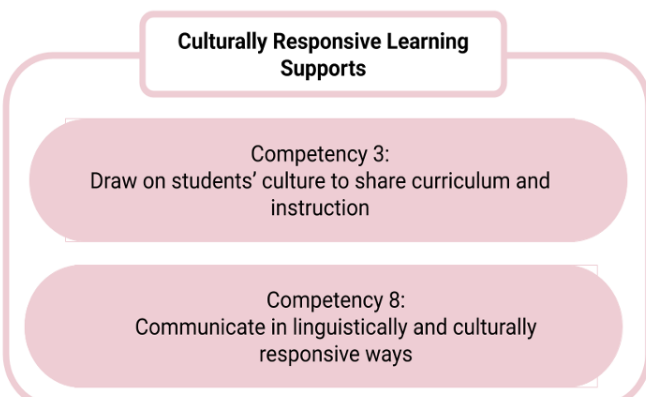


Figure 5. Competencies aligned with culturally responsive learning supports theme.

Serena utilized multiple learning strategies during her engineering design-based science lesson to promote communication in linguistically and culturally responsive ways. These methods included: (1) Sentence frames and graphic organizers to help students articulate their science and engineering ideas; (2) Scaffolds when introducing new science terminology; and (3) Incorporating students' heritage language in the classroom.

Serena demonstrated the use of sentence frames during the Identify and Describe stages of her CRED lesson, including phrases such as "I notice…"; "I wonder…"; "give me a describing word"; and "It affects humans or it affects people because…". These sentence frames provided scaffolding language support that benefitted all students, particularly MLs who needed additional language support. Additionally, Serena utilized graphic organizers during different stages of the CRED lesson to help students make sense of their ideas about air pollution and the engineering design process. For example, during the Describe stage of the CRED, Serena had students take notes on a thinking map while they were watching a video on air pollution. Prior to the video, Serena helped orient the students to the thinking map through the following conversation:

> Serena: "Who can tell me what type of thinking map that is?...A tree map. And we use that to classify information. How many categories do we have on our thinking map?"
> Student: "Four."
> Serena: "What are the titles?"
> Student: [Student read all titles from the tree map]. "Causes of air pollution; four types of air pollutants; what are some health effects of toxic pollutants?; and solutions to air pollution"
> Serena: "Very good. Eyes on the board. Does it look similar to this? [teacher points out a drawn image of the tree map on the white board.]
> Students: "Yes".
> Serena: "So we as a class are going to watch a video and while you are watching the video, I want you to take notes and fill it into your tree map…I want you to write as much as you can remember and as a group we are going to go ahead and have a discussion and we are going to fill it in together. I will pause the video and ask some questions, and that may give us some ideas to fill in the information."

By orienting the students to the thinking map prior to watching the video, all students were given time to understand how the tree map was organized, and how they were going to use it to record their ideas. This was especially helpful for the MLs in Serena's classroom as she recognized they may need extra time to process the information. During the video, Serena paused it multiple times to ask scaffolded questions to aid the students in capturing the important information regarding air pollution. For example, at the beginning of the video, Serena paused the video and inquired: "What did the video say about the causes of air pollution?" Students shared their ideas and Serena captured them on the tree map diagram on the white board. Following this, students were provided with additional time to write down any ideas they had not already captured on their individual tree maps. Ultimately, Serena used the tree map graphic organizer to not only provide all students with a scaffolded way to organize their ideas about air pollution, but also to allow them to make connections back to their "I wonders" about air pollution. In particular, after recording the causes of air pollution in their tree maps, Serena reminded the students "And remember, that was one of 'our wonders'. What causes bad air quality?". Ultimately, through using the tree map graphic organizer, Serena recognized that it would provide all students a visual representation of the information she wanted them to know about air pollution, which aided *all* students' comprehension of this complex topic.

Serena also used several different scaffolds when introducing new science terminology to her students throughout all stages of the CRED lesson. More specifically, Serena created additional context around new science terms and would repeatedly ask students about the meanings of different terms. For example, during the Identify stage of the CRED, Serena asked students, "Anyone want to explain the air quality index?" Later on, during the Identify stage of the CRED, Serena returned to the air quality index data that students were observing from their local community. By providing scaffolds for students to learn new science terminology, Serena provided all students with simple starting points to practice using these terms and make connections between their local place and the science terms.

> Serena: "What kind of weather…have we had in the last two days that might be a reason as to why we are seeing this air quality?
> 
> Students: "Fog. Thunder."
> 
> Serena: "What else?...And yesterday, we were affected by extreme weather because we had a rainstorm. We couldn't go outside and get our energy out. Anybody want to make a connection between the weather and the green [PurpleAir sensor value]? What connection do you see? I'll help you out with a sentence frame. I can make a connection between air quality and green because…"

In this way, these scaffolds served to make the science content more relevant to students' everyday lives, which was particularly important for Serena's MLs as they made sense of the new terminology.

Further, Serena urged her MLs to use their heritage languages during the entire CRED lesson and engaged in communication in Spanish with native Spanish speakers. She created various opportunities for these students to converse in their heritage languages throughout the lesson. Whether during whole-group instruction or in small group discussions, these students remained actively involved. Acknowledging her students' language abilities, Serena made sure that her emerging MLs comprehended all aspects of the CRED, such as local news clips and science content videos, and checked for understanding by speaking with them in Spanish. Furthermore, Serena often ended these discussions by translating the Spanish for the entire class, ensuring that all students felt at ease participating. By enabling students to use their native language, Serena's MLs were able to connect their personal experiences and existing knowledge to the science concepts being taught during the CRED lesson.

> Teacher: [speaks in Spanish]...aspiradora- a vacuum y que hace? [What does it do?]
> 
> Student: "basura, pon lo aqui" [trash, it goes here]…student continues sharing their response in Spanish.
> 
> Teacher: "Can you show me how it does that with your hand? What made you do this prototype? What made you think of this?
> 
> Students: "Because my dad- he works somewhere".
> 
> Teacher: "Where does he work? It is very important where his dad works."
> 
> Student: "He works in the fields.

Teacher: "He works in the fields and does he do the almond shaking?
Student: "Yes".
Teacher: "So he knows that there's a lot of dust…a lot of particles are flying around."
Teacher: "por qué hicieron esto?" [Teacher asks, why did you choose to do this?]
Student: "porque el aire aquí, y necesito bueno…" [Student says something to the effect of "because of the air here, and I need good air"].

### 5.3. Classroom Culture and Expectations

Instances coded as Competencies 5 and 6 resulted in the theme *classroom culture and expectations* (see Figure 6).

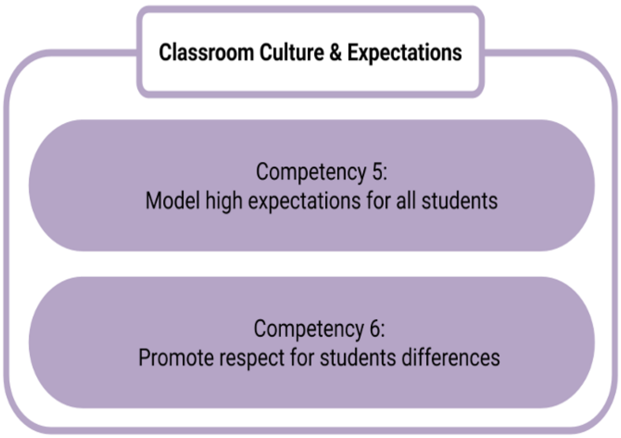


Figure 6. Competencies aligned with classroom culture and expectations theme

Serena excelled in establishing a classroom culture that sets high expectations for all students and promotes respect for the differences. To cultivate a classroom culture promoting high expectations for her students, she used multiple strategies. For example, she provided all students with time to think before communicating their ideas. In the Identify stage, she showed a local weather news video and asked her students to fill in a handout focusing on their notices and wonders about the video. She stopped the video at certain parts to give her students time to think about and write their notices and wonders. Another strategy is that she welcomed mistakes. For example, in the Describe stage, she asked students to create a poster about PM2.5 which is responsible for bad air quality. In preparing those posters, one of the students made a mistake and Serena comforted the student by telling them that it could be fixed later. Another example is after listing various types of extreme weathers, Serena asked students to tell how those affect them. One student raised his hand to share but after a long pause, he bravely shared that he forgot the idea that he had. Again, Serena comforted him by saying "You forgot, that's okay, If you remember, let me know." Also, when students were asked to write down their wonders after watching a video, not to discourage students with coming up their own wonders, Serena said "remember if we don't have any down, these are some good ideas and we can be writing them down." In addition to welcoming students' mistakes, she also challenged students with their thinking and perseverance through trial and error. In particular, during the Generate stage, she encouraged students to go deeper with their brainstorming by saying "I need more ideas", "Now, I need some wonders", and "There are no silly ideas". Also, during the Create stage, Serena helped students go through the iterative process of failing and trying so that they could persist with their design thinking when building their prototype.

Serena employed a variety of strategies to foster respect for all students, cultivate a positive classroom space that allowed students to think and gave them voice. She established a classroom culture where students could easily bring their attention back to her and other students. She often used the “echo, echo” strategy to allow students to understand what they were supposed to do and to reinforce the key ideas or questions the teacher wanted the students to think about and respond to. For example, during the Finalize stage, she used this strategy to reinforce her instruction.

> Serena: Let’s do three minutes to fill in the first three boxes. Echo, echo. What is the name of your prototype? [Students repeat the question] Echo stop. [Serena gives detailed instruction]
>
> Serena: Next. Echo, echo. What is its function? [Students repeat the question] Echo stop. [Serena gives detailed instruction]
>
> Serena: Echo, echo. How will this help our community with our problem? [Students repeat the question] Echo stop. [Serena gives detailed instruction]

Many times in the lesson, Serena expressed her appreciation when students were respectful of hearing and sharing other students’ different ideas. For example, as students shared their prototype during the Finalize stage, she said, “Thank you for those of you who are being quiet and respectful”. When Serena asked students what connection there would be between race track and air quality, students were collectively excited about sharing their ideas so she immediately calmed down the class by saying, “Thank you for raising your hand.”

Moreover, Serena was mindful of providing opportunities for students who had not spoken so by saying, “Who else hasn’t shared?” Also, she constantly gave time and space to ensure that all students were sharing their ideas and opportunity to speak. Also, to hear as many voices as possible, she asked, “Anything else?” and provided wait time to encourage other students to provide suggestions on how to improve one student’s prototype. In addition, multiple times, she physically moved to the students who were speaking softly and asked them to say it again when she was close by or she repeated what they said for the rest of the class rather than making them speak louder.

Serena was flexible in adapting her instructional approach to align with her students' interests. She allowed discussions to go in a direction that were not originally intended. But, she skillfully guided the conversation back to the original topic, ensuring a balance between students’ interest and the topic of the lesson.

> Students: There’s Mexico. Vegas. [Collective] OOOOOOOOOh!
>
> Teacher: Oh, a purple…Sit down. I will go to where the purple is at…[after Zooming in the air quality map] Can you give reasons of what may be going on there?

She also practiced cultivating a positive classroom space during the Finalize stage. When students' feedback had some tension, she reminded students that "we're not telling them anything that's bad. We are just giving them ideas. Maybe you should add [blank], or you should do this to make it even better."

**6. Discussion**

When organizing the findings to answer our research questions "*How does Serena embed community throughout all phases of the Culturally Relevant Engineering Design (CRED) Framework?*" and "*How does Serena support multilingual learners (MLs) as she teaches engineering?*", it became evident that there were connections across the three themes which were woven together to create Figure 7. As noted within the innermost circle of the figure, Serena used multiple pedagogical strategies throughout each stage of the CRED, and these strategies aligned with six of the eight competencies for supporting MLs. Also, denoted within the innermost circle, Serena created a classroom culture of respect and held high expectations for all of her students. These learning supports and classroom expectations were all embedded within the larger community context (i.e., the outermost circle), which shaped the way that each of these themes manifested within Serena's classroom.


Figure 7. Interaction of major themes

Throughout the planning and enactment of this particular CRED lesson, Serena made purposeful connections to the community, embedded across all stages of the lesson. She used the topic of extreme weather that was provided by the research team as a springboard for connecting to an issue of importance for the students in her classroom. She could have investigated flooding or drought, but instead purposefully chose to take what the students mentioned about dust storms that were fueled by almond harvesting and connect that to the important local issue of air pollution. By doing so, she leveraged students' rural cultural wealth connected to their experiences living and interacting with family members who work in the orchards. Crumb et al., [36] proposed the "rural cultural wealth," framework which is built upon the concept of community cultural wealth in an ecological context [25]. This framework recognizes and values the strengths and resilience of rural people. The rural cultural wealth conceptual framework is based on the belief that rural residents possess multiple strengths and resilient strategies. As students learn through interacting with their families and local environments, they build local rural knowledge [27] which can provide powerful opportunities for teachers to connect students' background knowledge with in-class learning.

Serena leveraged multiple opportunities to activate students' background knowledge connected to the local context throughout all stages of the CRED lesson, such as when she projected the PurpleAir sensor map. Students were excited and engaged in the session (as they were throughout the entire learning sequence), as they connected the air sensor data to their personal experiences with and knowledge of places on the map. As the students were making observations of the sensor values, Serena prompted them to infer why the different areas had different air qualities. In making their inferences, students activated local knowledge of the surrounding geography, industry, and air flow patterns from wildfires to make sense of the sensor data. Serena also engaged students in interviewing the school nurse and bus driver, positioning these community members as expert knowledge holders. As Serena closed out the Describe stage of the CRED, she reminded students of the "evidence" they had collected through their "research" efforts, including watching local news footage, interviewing community members, and interpreting the PurpleAir sensor data. Through this exchange, Serena was making explicit connections between the engineering "research" students were conducting in class and the knowledge they and community experts held connected to the problem. By doing this, not only was Serena positioning her students as knowledge generators, but by connecting local knowledge with classroom practices, she was able to increase student engagement in engineering. This increased engagement due to connecting local knowledge and classroom activities has been shown to increase students' understanding of science and engineering [37-39]. The weaving of community context and students' experiences throughout the lesson required a deep understanding of and focus on the community in which her students resided.

Serena's teaching approach for her MLs is rooted in culturally responsive care. During the CRED lesson, she integrated an instructional style and a set of expectations designed to promote high levels of student achievement, showcasing a blend of concern, compassion, commitment, responsibility, and proactive engagement for her students. She recognized her students' linguistic abilities from an asset perspective and fostered a classroom culture that encourages communication in their heritage language, both formally and informally. As students collaborated in small groups on daily tasks, they were able to converse in Spanish, effectively reducing the linguistic barriers that MLs often face in educational settings [40], [41]. Beyond facilitating peer interactions in Spanish, Serena translated Spanish into English for her emerging learners and engaged in one-on-one discussions in Spanish with several students. This focus on linguistic freedom allowed MLs to express themselves openly, contributing to a more inclusive environment. "By seeing, respecting, and assisting diverse students from their own vantage points, teachers can better help them grow academically, culturally, and psycho-emotionally" [31].

Additionally, it can be said that teachers who genuinely care for their students recognize their humanity, hold them in high regard, expect high performance, and employ strategies to meet those expectations [31]. By acknowledging the linguistic assets of MLs as strengths, Serena was able to foster her students' confidence and curiosity during the CRED lesson. By instilling a habit of inquiry, all of Serena's students, particularly the MLs, developed into emerging researchers and scientists. Serena promoted linguistic expression, thereby enhancing the engagement of these learners in engineering education. By providing opportunities for all students to comfortably practice new vocabulary, such as "particulate matter" and "emission," Serena was addressing the needs of her students, supporting their self-esteem, autonomy, intellectual growth, and academic success through culturally responsive caring practices.

There were several overlaps in the strategies Serena utilized to support high expectations of all students that also supported her MLs. For example, while establishing a classroom culture that promoted high expectations of all learners, Serena provided students with time to think before communicating their ideas; welcomed mistakes; encouraged students to utilize complete sentences when sharing their ideas; and challenged their thinking. These strategies were not only effective at establishing high expectations for *all* students but also provided additional support for ML students. By providing MLs with additional time to think before attempting to communicate their ideas, Serena gave them time to mentally process information in their heritage language, translate it to the language they were speaking, and formulate more accurate responses. Further, Serena created a classroom culture where her students were encouraged to make mistakes. This provided more space and time for them to think critically about concepts they were learning about (e.g., emissions; etc.), which was also important for MLs as they could actively engage with the concepts and language, identify areas of improvement, and learn more effectively by correcting their own mistakes [4]. By cultivating a culture where mistakes were accepted, Serena's classroom space was rooted in culturally responsive care [31]. Additionally, Serena provided sentence frames to aid students in using complete sentences to communicate their ideas. Although helpful for all students, this strategy was especially helpful for MLs because it gave them additional practice using the language they were speaking in, while challenging them to meet a high standard [31]. In this way, there were multiple connections between the strategies Serena used to support high expectations of all students and the pedagogical approaches she emphasized in teaching her ML students.

Further, in challenging students' thinking, Serena centered community connections. She did this by asking follow up questions such as, "What else? What other weather have we had in the last two days that might be a reason as to why we are seeing this air quality?" and "How will this [design] help our community with our air pollution problem?". These follow up questions prompted students to make connections between what they were learning about air quality and their local weather as well as think about how their design solutions could improve the air quality in their community. As a result, Serena not only leveraged students' community cultural wealth [37], but also prompted students to extend their thinking and understanding of the science and engineering concepts they had learned throughout the multi-day CRED lesson.

Ultimately, Serena embedded authentic community connections throughout all stages of the CRED process. Through blending different culturally and linguistically responsive competencies and community connections, Serena provided genuine opportunities for all her students, especially her MLs, to develop their science and engineering knowledge and language skills within a meaningful engineering education learning environment [4], [5]. This is significant as Serena's approach at keeping community central in her engineering instruction marks a notable departure from how other in-service elementary teachers embed community within engineering design-based lessons [21], [22]. Although prior literature has identified the need to create engineering design tasks that are human-centric and individual- and communal-sensitive [42], often these aspects are integrated within the beginning problem-scoping and final solution communication stages of the engineering design process [43]. Yet, by embedding relevant community connections throughout *all* stages of her multi-day CRED lesson, Serena took a novel, holistic approach to immerse her students in engineering design. By consistently referring students back to how their [design] would affect "our community", she was ensuring that they were considering the problem from a holistic, humanistic lens, rather than merely focusing on a set of criteria and constraints that the design must achieve. While meeting the criteria were important, Serena's approach ensured that a focus on criteria did not overshadow the reason for engaging in design in the first place - to address an important local problem.

The community connections Serena made to her students' small, rural community also highlight the importance of understanding how rural communities are different from one another [26]. For example, Serena continually helped her students make connections between the almond farming that takes place within their specific rural community and the resulting poor air quality. This is significant as it highlights a problem that is specific to a particular rural community, and not necessarily shared across multiple rural communities. Additionally, the explicit community connections Serena made to her students' rural community demonstrate her local rural knowledge [27] of what makes their community geographically and economically unique, while providing additional relevance to her students' and their families' lives. In this way, Serena embodies culturally responsive care in her approach to elementary engineering education [31].

## 7. Conclusions and Next Steps

Serena developed and implemented a multi-day engineering task focused on air pollution that lasted approximately 3.5 hours split across seven sessions. Through analysis of the video and lesson plan, we identified specific examples in each stage of the CRED where Serena purposefully connected classroom instruction to the local context and embedded specific ties to her students' community and culture during each lesson session. Serena also utilized various strategies to support MLs throughout the lesson sequence, such as drawing on students' culture to shape instruction and communicating in linguistically and culturally responsive ways. Our findings show the breadth of impactful strategies, approaches, and instructional moves employed by Serena that highlight ways community, context, and multilingual scaffolds can be meaningfully woven throughout each stage of the EDP with elementary students. Serena was able to take what she learned in the PL about using the CRED Framework to develop and implement community connected learning experiences to support her MLs. While the current study focused on a single teacher, it does highlight the potential use of PL to introduce teachers to culturally relevant engineering design frameworks (e.g., CRED) that can offer scaffolds to support engineering learning for all students. As classrooms evolve, Serena's culturally relevant approach to engage students by linking their background knowledge and community context with in-class learning can serve as a model for other teachers.

Our study describes our analysis based on observations of these components of culturally relevant engineering instruction, and next steps for this research will include follow-up interviews with Serena to better understand her perceptions and intentions related to her engineering lesson design and instruction. Furthermore, due to the nature of Competencies 1 and 2 being self-reflective and self-reported, we are not able to observe their presence without consulting Serena herself. By providing Serena the opportunity to describe her thinking throughout her lesson implementation and to reflect on specific moments throughout the recorded lesson, we will be able to provide deeper analysis and more explicit description of the enactment of culturally and linguistically relevant engineering design strategies that can add to both the larger body of existing research and inform future teacher professional learning.

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