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Improving STEM Education through Resource Activation: A Study of Culturally Relevant Teaching for Critical Data Literacy in a High School Science Classroom

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Abstract: Interest in promoting data literacy among K-12 students has grown, driven by the need to cultivate skills in using data effectively across various fields of study. Integrating discipline-specific curricula, like bioinformatics, which merges biology and informatics, can broaden student engagement in STEM. While earlier efforts focused on technical data skills, recent research emphasizes a sociocultural approach to encourage critical data literacy, aligning with culturally relevant teaching (CRT). This study investigates a teacher's instructional practices for CRT in prompting critical data literacy. We used a resource activation framework that aims to explore the ways in which a teacher utilized material resources (tangible objects and tools), cultural resources (knowledge and skills), social resources (interactions and relationships), and symbolic resources (recognition and prestige). We worked with a science teacher, Tracy, who activated resources to adapt and teach a bioinformatics problem-based learning curriculum rooted in real-world problem-solving in STEM, connecting students with community issues, such as asthma and air quality. We deductively analyzed classroom observation notes, interviews, and recordings of the professional development workshop sessions. We found that during the curriculum implementation, Tracy activated cultural and social resources to enable access to other resources that were not readily available. Our findings suggest that the activation of cultural and social resources concurrently allowed the teacher to address diverse student needs, foster relevance and engagement, collaborate with colleagues, and continuously enhance their teaching practices. Ultimately, activating all four resources empowers teachers to provide high-quality instruction, leading to improved overall STEM education.

Keywords: STEM Education; Culturally Relevant Teaching; Critical Data Literacy; Resource Activation.
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Introduction

Recent years have witnessed a growing interest in engaging K-12 students in data literacy. Data literacy refers to the ability to formulate relevant questions that can be answered with data, select and use appropriate analyses, and make data-based inferences and arguments while considering the contextual factors influencing the production of data (National Governors Association, 2010; NGSS Lead States, 2013). Moreover, due to the extensive growth of data use across various disciplines, including but not limited to STEM (science, technology, engineering, and mathematics) subjects, we need a skilled workforce capable of harnessing this data to generate valuable insights into complex problems, innovative solutions, and informed decision making. Incorporating discipline-specific curricula in the emerging field of bioinformatics, which integrates biology content and informatics (i.e., the science of using data to improve human health), can broaden students' participation in STEM (Kovarik et al., 2013; Kulikowski et al., 2012).

Critical data literacy extends the data literacy concept by going beyond technical competencies to focus on a deeper, more analytical understanding of data. This form of literacy, informed by critical pedagogy as advocated by Paulo Freire, involves questioning data's apparent objectivity investigating its broader societal implications (Stornaiuolo, 2020; Wilkerson & Polman, 2020). Critical data literacy is not just about data comprehension; it also involves critiquing data as a socially constructed entity that can perpetuate biases and exclude certain groups (Philip et al., 2016; Vakil & Ayers, 2019). This perspective aligns with recent shifts in educational research that emphasize students' development of situated knowledge, identity, community, and participation, and that encourage critical reflection on broader social and cultural contexts (Kafai & Proctor, 2022; van Wart et al., 2020). For example, van Wart and colleagues (2020) analyzed participatory mapping activities by engaging young people in collaborative efforts to address local community challenges, such as air quality and park planning. The study's finding highlighted the significance of community engagement and the importance of creating a collaborative space for critical data literacy activities. Similarly, Stornaiuolo (2020) developed curricula centered on personal data, which included initiatives in data storytelling that utilized data collected from students' daily lives. These approaches not only enhanced student engagement but also established a direct connection with data. These interventions emphasize the importance of contextualizing learning activities in ways that recognize students' experiences and identities as valuable resources for generating meaningful knowledge about data.

Adopting a sociocultural approach is crucial in supporting students' critical engagement with data, which involves acknowledging that their acquired values and interests play a significant role in learning, enabling them to connect ideas and concepts to their own experiences. Culturally relevant teaching (CRT) following Ladson-Billings' description (1995; 2016) plays a pivotal role in this context. CRT emphasizes the importance of establishing cultural connections in students' learning. It includes recognizing their communities, designing culturally diverse lessons, and valuing various ways of knowing (Gay, 2002). Embedding critical data literacy within CRT is vital to allow learners to engage with their cultural backgrounds in meaningful ways (Tissenbaum et al., 2021).

Despite recognizing the potential in using culturally relevant activities to enhance critical data literacy, there is limited insight into how teachers comprehend and implement these concepts, especially when integrating new pedagogies or curricula (Wise, 2020). This research gap emphasizes the need to explore how teachers maximize their use of resources. Addressing the gap necessitates examining teachers' access to resources, such as data, curricula, and training workshops opportunities for adapting curricula to complex classrooms with cultural dynamics (Oceans of Data Institute, 2015; Sadler, 2004). Investigating the instructional strategies and resources supporting CRT for critical data literacy is therefore essential.

The research reported in this study builds on an NSF-funded project aimed at integrating bioinformatics into the standard high school biology curriculum. This case study, which features a teacher named Tracy, focuses on her utilization of culturally relevant resources to implement the curriculum. Using the resource activation lens proposed by Rivera Maulucci (2010), we investigate Tracy's related instructional practices to understand how she applied the unit in a culturally relevant way to engage students with data on topics that were important to them. The research questions we investigate are as follows:

1. How does Tracy's resource activation contribute to supporting CRT in the curriculum, and which types of resource activation are most and least prominent?
2. In what ways do different types of resource activation relate to each other in order to effectively support CRT in the curriculum?

Theoretical Framework

In this section, we present a more detailed discussion regarding the importance of conducting research on CRT and the educational resources required for STEM instruction. We start with a review of recent studies that explore the integration of CRT in STEM educational settings. We then provide an overview of the resource activation conceptual framework that serves as the foundation for this study.

Culturally Relevant Teaching

CRT is a pedagogical approach by which teachers intentionally incorporate academic content and the learning process to affirm diversity and empower students to question prevailing norms (Ladson-Billings, 2000). This term was initially introduced as a method for teachers to better engage with African American students and others who were not being reached effectively by public schools (Ladson-Billings, 1995). However, CRT has since evolved into a deeply consequential instructional strategy suitable for all students (Underwood et al., 2018). This is because it offers a structure by which teachers can foster students' critical thinking abilities and promote a sense of civic responsibility and humanity. It accomplishes this by using the teaching material to expose hidden curricula, societal norms, and injustices (Ladson-Billings, 2000). Consequently, CRT is a teaching strategy in which educators go beyond fact memorization and instead, they empower students to scrutinize new information and devise solutions to societal issues. It does so in a way that uniquely stimulates students in both dominant and non-dominant groups to achieve the highest academic performance levels per Bloom's taxonomy (Brown-Jeffy & Cooper, 2011).

Moreover, CRT is an educational concept that emphasizes the importance of incorporating students' cultural backgrounds into all aspects of learning. The term "culture" is understood as the shared traditions and understanding of the communities with which students associate with (Gutiérrez & Johnson, 2017). This implies that culture is not solely about the racial or ethnic group with which a person identifies, but also encompasses other communities to which they belong, such as their neighborhood or circle of friends. This definition sees culture as a flexible construct, evolving as the individuals within the group change and progress over time (Gutiérrez & Johnson, 2017; Paris & Alim, 2017). Notably, this perspective on culture rejects static portrayals based on historical practices or confined to shared racial or ethnic origins. Instead, it focuses on current expressions of culture and cultural comprehension, acknowledging culture's complexity and dynamism as well as the diverse cultural identities students possess. CRT in bioinformatics serves as a bridge connecting the rigorous, data-focused nature of these fields with the varied cultural experiences of students. The integration of CRT in bioinformatics is not merely about contextualizing curriculum content; it is about engaging students in scientific inquiries that are directly relevant to their cultural narratives and experiences. For example, this approach could involve examining asthma datasets that reflect students' community health issues or the environmental challenges pertinent to their localities (Yoon et al., 2022). Through this contextualization, CRT not only deepens students' engagement but also fosters an environment in which cultural diversity enriches the scientific learning process.

Research on CRT can also be found across various subjects like math (Adiredja, 2019; Gutiérrez, 2013; Thomas & Berry III, 2019), science (Barron et al., 2021; Erickson, & Gutierrez, 2002), English language arts (Lee, 2001), and computer science (Kafai et al., 2014; Scott et al., 2015). For example, Thomas and Berry III (2019) conducted a systematic review of 12 articles selected among 1224 articles using a qualitative metasynthesis approach, identifying five key CRT practices in math education. These practices were: demonstrating care by respecting students' culture; applying knowledge of contextual teaching practices; employing cultural competency in instruction; maintaining high expectations for student growth; and delivering mathematics instruction with strong teacher efficacy. In accounting for teaching strategies, CRT in math requires teachers to prioritize student-centered and inquiry-based strategies that empower students to own their learning and connect personally with mathematical content. Applying CRT in science education also involves specific strategies. According to Barron et al.'s (2021) study, one approach is for teachers to initiate a tangible activity, establish related vocabulary, and link it to an inquiry investigation based on a scientific phenomenon. This approach fosters a shared understanding of relevant terminology, empowers students to engage in critical discussions, and promotes inclusivity within the learning environment (Johnson, 2011; Mensah, 2022).

In the context of bioinformatics and broader STEM fields, critical data literacy extends beyond fundamental data manipulation to encompass the critical appraisal of data by acknowledging its ethical and societal dimensions. This aspect is crucial in bioinformatics, where data interpretations can significantly influence societal well-being and ethical considerations (Pieterman-Bos & van Mil, 2023). For example, this involves researchers and practitioners critically evaluating the sources of data, considering the potential biases and limitations in the data collection process, and being transparent about these aspects in their analyses and interpretations (Bain et al., 2022). It also involves engaging in ethical discussions regarding the potential societal impact of their findings, especially in fields such as healthcare, genetics, and environmental studies, where bioinformatics plays a crucial role.

To gain a comprehensive understanding of CRT incorporation in high school STEM classrooms, further research is needed to specifically investigate the experiences, challenges, and strategies of in-service teachers. This is necessary in part because there is a lack of empirical studies that specifically examine the application of CRT in the context of critical data literacy (Stornaiuolo, 2020). By building upon the existing literature, this study aims to bridge the gap between theory and practice, providing valuable insights for professional development (PD) initiatives targeting practicing teachers.

Educational Resources and Resource Activation

Teaching science through investigations, as advocated in current reform documents in the U.S. (NGSS Lead States, 2013), requires teachers know how to effectively utilize and organize materials to facilitate students' construction of knowledge during engagement in scientific practices (McNeill et al., 2016; NRC, 2006). Therefore, success no solely on teachers' subject matter expertise, but on their ability to activate diverse resources within their environment for successful implementation of STEM. Rivera Maulucci (2010) has addressed these enactments in terms of four distinct resource types: material, cultural, social, and symbolic resources. In this context, "activation" refers to the intentional use and adaptation of knowledge, as well as to commitments to improve pedagogical strategies and support teaching practices.

In educational settings, the term *material resources* encompass various elements such as "equipment (e.g., computer technology, science supplies), time (e.g., time available for teaching, time for collaboration among teachers), and funding (e.g., expenditures for school personnel and other purposes related to teaching and learning)" (Lee et al., 2016, p. 770). These resources can range from well-organized educational curricular materials that outline the scope and sequence of instruction to informal resources like worksheets shared by colleagues (Grossman & Thompson, 2008). *Cultural resources* are "knowledge, skills, education, and experiences within particular contexts" (Rivera Maulucci, 2010, p. 824). In an educational setting, cultural resources include understanding the students and the teaching context; teachers' knowledge and conceptual understanding of data literacy (e.g., context, variability, aggregate, visualization, and inference); teachers' pedagogical and instructional strategies to foster critical data literacy, the school's preferred instructional approach (e.g., problem-based learning, inquiry-driven learning, culturally relevant pedagogy); students' knowledge, experiences, language, and academic abilities; and the overall culture of the school. The term *social resources*, or social capital, refers to the direct and indirect relationships, networks, community, and support systems that contribute to decision-making in teaching and learning (Yoon et al., 2017; Lee et al., 2016). In an educational setting, social resources include opportunities for teachers to develop trust, friendships, and agency with other teacher colleagues, mentors, and school leaders. Social resources, both within and outside the school context, can affect teacher learning and development (Luft et al., 2015). Finally, activating *symbolic resources* is the fourth important aspect for teachers to consider. Symbolic resources "arise from recognition or prestige associated with a cultural value" (Rivera Maulucci, 2010, p. 842). In an educational setting, symbolic resources pertain to the perceived status or importance placed on teaching and learning, such as the emphasis placed on critical data literacy relative to other curriculum areas and the recognition or celebration of student achievements in learning critical data literacy. Moreover, symbolic resources highlight the institutional social value assigned to different forms of instruction, the prioritization of critical data literacy in various content domains, and the recognition of teachers' efforts to integrate critical data literacy into their existing curricula.

Literature investigating multiple types of resources indicates that teachers often utilize various types of resources simultaneously, suggesting that these different resources can be mutually supportive of each other. For example, one study found that the introduction of curricular materials (material resources) during a PD program (a social resource) helped to mitigate the perceived hindrance of limited material resources among teachers (Lee et al., 2016). This indicates that the social resource of the PD program improved teachers' access to material resources. Another study, by Rivera Maulucci (2010), demonstrated that teachers could leverage the social resources provided by their colleagues and support systems to acquire material and human resources, thereby enhancing their science teaching. While these studies shed light on the interaction of resource types, further research is needed to gain a broader understanding of how teachers, especially those who are unfamiliar with the curriculum, interact with resources in their specific contexts. Many existing studies have focused on investigating only one type of resource, despite evidence suggesting the interaction between different categories of resources play a critical role in teaching (Diamond et al., 2014; Fischer et al., 2018; Johnson, 2011). Exploring multiple resource categories simultaneously can provide a more comprehensive understanding of how contexts either support or hinder teachers.

Methodology

This study investigated how a teacher activated resources for CRT to promote critical data literacy in a science classroom. We adopted a case study approach, as described by Yin (2017), to provide an intricate and contextualized understanding of the teacher's resource activation within their real-life instructional setting. The case study method is particularly appropriate for preliminary investigations into phenomena, when a phenomenon has not yet been extensively studied or where there are complex variables involved that benefit from detailed, contextual analysis (IES & NSF, 2013). Specifically, we chose the case of Tracy, the teacher in this study, to illuminate the intricacies of integrating an 18-lesson curriculum in a science classroom, providing rich, descriptive insights that can inform future research and practice.

Context

K-12 Bioinformatics Curriculum

The curriculum, consisting of a total of 18 lessons, was designed to be implemented as an in-person program in 2019, spanning approximately 20 hours of instruction. The full scope and sequence of the curriculum is shown in Appendix A. The entire curriculum is grounded in real-world problem-solving, engaging students with the issue of asthma and air quality. This topic was chosen because it is highly relevant in an urban environment, particularly among students of color (Bryant-Stephens et al., 2012). The curriculum is divided into three parts. At the beginning of the lessons (i.e., lessons 1 and 2), students are introduced to a specific problem-based learning (PBL) scenario (Figure 1), which focuses on the issue of high asthma rates in their local community due to low air quality in cities.

Figure 1

Bioinformatics Problem-Based Learning Unit Scenario

There is a rising case of asthma in urban areas in the United States. Researchers have hypothesized that air quality contributes to this phenomenon. However, there may be a number of other causes, including a rise in smoking rates, industrial pollutants, and social stress from a lack of access to life resources. The Town Council of [redacted] has announced a new community program that will fund projects that are likely to support risk reduction of local asthma cases. These projects may include planting more trees to purify the air, an anti-smoking campaign, and building a park to promote activities that can alleviate stress. The Town Council asks you to research the issue and submit a proposal describing a project that your team would like to fund with evidence from public health and environmental data that supports your proposal.

In the second part of the lessons (i.e., lessons 3 through 15), to investigate the problem, students collect, analyze, and visualize air quality data, such as particulate matter 2.5, carbon monoxide, temperature, and humidity through a mobile app and sensors (Figure 2) in various locations within their community. Students then compare their collected data to data from a national air quality dataset, which they also analyze to understand how factors in the exposome are in various geographic locations that are tied to socioeconomic issues, and how they impact health. In the third part (i.e., lessons 16 through 18), students are encouraged to design intervention and action plans appropriate to their local area to ameliorate environmental conditions. This series of curricular lessons was purposefully designed to support students' learning of critical data literacy through CRT. Each lesson's materials include a teacher lesson plan, a class PowerPoint slide, and student worksheets.

Figure 2

Devices that Students Used to Collect Air Quality Data

Teacher Summer PD Workshop

The research team organized a three-week, in-person summer PD workshop in July 2019. It lasted about 75 hours in total and involved six teachers from the school district. In the first week, research partners from the medical school introduced teachers to bioinformatics research. Core concepts like the interaction between the human genome and exposome were covered (Figure 3), along with real-world examples such as bioinformatics investigations of asthma and air pollution in urban contexts (Figure 4). The second week involved smaller group work, during which teachers adapted and constructed curricular units to align with their existing curricula, local students, and state standards. During the third week, teachers piloted their units over three days with high school students in our summer program. The PD workshop dedicated time for discussion and sharing, which were held in morning and afternoon sessions to provide space for reflection and time to engage in community-building activities (see Darling-Hammond et al., 2017). The Saturday PD workshop sessions were conducted during the school year to assist teachers in navigate lesson plans and PBL resources.

Participants

Every teacher in the PD workshop was an expert teacher who were nominated by the director of science in the school district. In line with the Institute of Education Science and National Science Foundation educational research continuum (IES & NSF, 2013), our initial investigation selectively involved a small group of science teachers. This approach enabled us to conduct a focused and detailed exploration of contextual developments, which is crucial for developing the depth and richness required in early-stage exploratory research.

Figure 3

A PowerPoint Slide to Introduce the Exposome

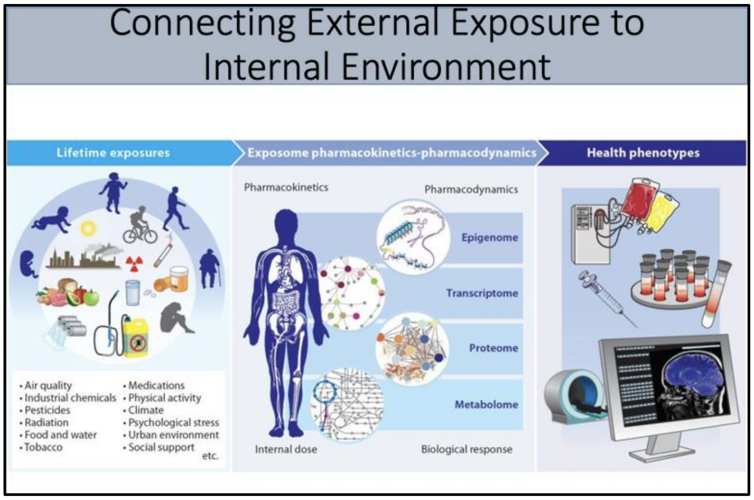
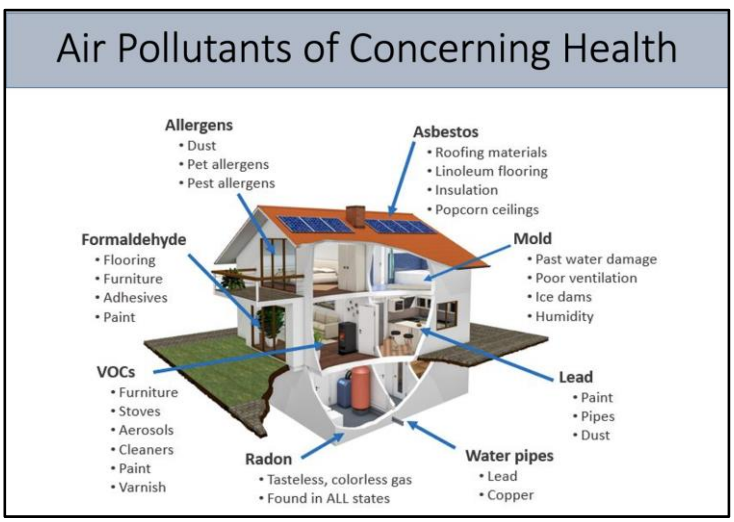


Figure 4

A PowerPoint Slide of Indoor Air Pollutants



Case Study Teacher: Tracy

Of the teachers who participated in the PD, we selected one in particular for further investigation. Tracy identified herself as African American and Egyptian, and was the environmental science (ES) teacher in a public high school located in the northeast U.S. We chose Tracy for this case study due to a combination of factors that made her particularly representative and insightful for our research objectives. First, being in her fifth year of teaching, Tracy was not a novice teacher and we wanted to learn from a teacher who already possessed a level of classroom experience. Second, her enthusiastic participation in the PD workshop and her expressed interests in providing authentic and meaningful learning experiences in her class aligned well with our research goals. For example, on the pre-PD survey, she responded by saying, “I hope that I complete the PD with more knowledge, with something I can take back to my students in the classroom. Something that is real life, relatable to my students, and hands-on.” This comment highlighted her strong desire to improve science teaching by including real-life applications and hands-on learning experiences. These attributes, coupled with the collaborative spirit she exhibited the later stages of the PD, made Tracy an exemplary participant for a detailed case study that could yield rich, nuanced insights into the integration of bioinformatics in a high school science classroom.

In the school in which Tracy taught, 354 students enrolled during fall 2019, of whom 82% are recognized as socioeconomically disadvantaged. The ethnic distribution of students attending the school is as follows: 90% African American, 5% Hispanic, 1.4% White, 2% being of two or more ethnicities, <1% Asian, and <1% American Indian/Alaska Native. Approximately 13% of students were enrolled in Individualized Education Programs (IEPs), which are custom-tailored educational plans designed to meet the unique needs of students with disabilities, and 2% were considered English language learners.

Data Sources

This research draws on four data sources to build a case study of Tracy’s strategic resource activation. These are classroom observations, implementation debrief interviews, a post-implementation interview, and recordings of school-year PD workshop sessions. As part of the larger bioinformatics project, Tracy was assigned a school-year facilitator who was responsible for collecting, organizing, and conducting classroom observations during implementation. *The classroom observation* protocol includes descriptions of the classroom context and condition, descriptions of the classroom interaction and Tracy’s instructional practices, and reports on the instruction and activities taking place, including the materials given out to the class. Tracy’s class was observed in nine of the 14 classes devoted to this project, which totaled 16 hours of instruction. The observation ranged in length from 33 minutes to 55 minutes with an average length of 46 minutes. *The open-ended debrief interviews* were conducted using open-ended interview protocols to gather Tracy’s impressions of the lesson and to gain insight into the rationale behind specific instructional decisions she made. A total of seven informal interviews were conducted after the lessons and audio were recorded. The duration of the interviews ranged from four minutes to 17 minutes, with an average length of nine minutes. *The semi-structured post-implementation interview* was conducted to explore the variety of ways in which Tracy identified resource gaps, planned their teaching, and taught within the existing science unit. It also allowed us to probe her experience as it related to the research goals, learn about Tracy’s perspectives on the success of their implementation (e.g., What was the most significant difference compared to [how you taught the class last year]?), and issues that she felt needed activation of resources (e.g., What were some of the challenges that emerged during the implementation?) followed by what she felt about available resources (e.g., How do you feel about [how you utilized] onsite support?). The interview was conducted virtually via an online meeting platform (www.bluejeans.com) and took 67 minutes. *The Saturday PD workshop sessions* were conducted during the school year to provide opportunities for teachers sharing their experiences and addressing any questions related to lesson implementation. The research team led these sessions, which were held virtually and recorded using the online meeting platform. The workshop sessions had a duration of 115 minutes. Recordings of the sessions in which Tracy participated were used to capture the comments and questions she shared during the implementation.

Data Analysis

We qualitatively analyzed transcriptions and recordings of the data sources to identify instances that demonstrated resource activation in the four categories of material, cultural, social, and symbolic resources. The process of coding episodes involved a deductive approach.

Identifying and Logging Episodes from Data Sources

We began with video data and marked the episodes that captured the moments (1) when Tracy's activation of resources was apparent and (2) when activation of those different resource types was mutually supportive of or leveraged to access another resource type for instructional use. Our decision criteria for when to end an episode were primarily topical. When interactions between Tracy and a single student or multiple students shifted to different purposes or moved away to focus on different instruction, we ended the episode and began another. For the selected episodes, we created a finer-grained resource activation log and constructed a minute-by-minute log of each episode that indicated the moments, in which when Tracy interacted with students (e.g., launching the lesson or facilitating whole-class discussions). This step was necessary because our study is concerned specifically with the way in which Tracy activated resources during and for the instruction. After the episodes were identified and logged, we drew from interview data and revised lesson plans to round out each episode with pertinent data from other sources. To be attached to an episode, additional data had to pertain to it directly, such as (1) the excerpts from the post-implementation interview when she spoke about the class implementation, (2) the excerpts from debrief interviews when she spoke about the class implementation, or (3) the lesson plan that was adapted to that implementation from PD resources. Table 1 provides a breakdown of the number of codable episodes of resource activation extracted from the four data sources.

Table 1

Number of Codable Episodes for Each Data Source

Data source	Classroom observations	Class debriefs interviews	Post-implementation interview	School-year PD workshop	Total number of codes
Number of Episodes	30	10	15	24	79

Coding Episodes

We began by coding episodes using a coding scheme based on the four resource types—material, cultural, social, and symbolic. The coding manual construct with examples from data can be found in Table 2. There, we provide two examples in the cultural resources and social resources categories. The first is for the resource activation supporting CRT, and the second is the resource activation that contributed to make the other resource type accessible. In this case study, Tracy's activation of material and symbolic resources to gain other resource type due to its unavailability were not found.

The following is a transcribed example from a video recording that provides more details about how the codes were assigned. The episode starts with Tracy asking the whole class to explain their definition of genotype and phenotype:

1	Tracy	What's genotype and phenotype?
2	Jannah	[in a smaller voice] The gene [is] what makes you up…and phenotype is what you see!
3	Tracy	Mm-hmm [affirmative], so what's the relationship between genotype and phenotype?
4	Student	Genotype is genetic usage.
5	Tracy	So genetic make up. What's phenotype?
6	Students	*[Students share all together in a smaller voice]*
7	Tracy	That's what you actually see, right? What you actually observe. So what's the relationship between the genotype and the phenotype?
8	Student	The genotype is the genetic construction of phenotype.
9	Tracy	Which will...?
10	Student	Code for the phenotype.
11	Tracy	Um… you can [pause] listen to a song, but the melody is what makes it a song, right? So, your genetics or we can see it as a feature.
12	*Students nod.*	

In this dialogue, after a few exchanges, Tracy sensed that students were still confused with the terms genotype and phenotype (lines 1–9). She then used the relationship between melody and song as a metaphor to explain the relationship between genotype and phenotype (line 10 and 11). Here, Tracy used an example that was familiar to students that supported their understanding and made the concept more relatable. The use of accessible metaphors demonstrates her cultural knowledge of her students. Therefore, we coded this episode as belonging to 'cultural resources.'

During the analysis, we also marked moments when notable *contribution* occurred between resource types. It is important to note that to avoid code blurring when activating multiple resources, double codes were only assigned when a resource was activated to complement or to open access to another type of resource. Below is an example from observation notes that highlights Tracy's use of social resources when she encountered a Wi-Fi access issue and insufficient staff support.

> Students are about to go out when they realize they cannot get onto Wi-Fi. Tracy has to call the office to get the Wi-Fi password, never gets an answer and so signs each group in with her own password (12/13/2019).

During the debrief interview, Tracy explained that the school did not have full-time staff for the school's technology and the technician visited the school twice a week. She added that the technician was "always not available" because he was too busy when he was on-site. However, in the follow-up interview, Tracy commented,

> I mean, everyone was helpful, right from [blinded] to Stella to Blake, everyone was more than welcome to support us and support the students. So, when you come or come across a needles problems, I would like to, first thing is to, reach out to you guys, that you can, because you guys are really supportive in the project (5/1/2020).

Even though Tracy was not able to receive technical support in a timely manner, she was able to overcome the challenge with the research team's support, which was a *social resource* from beyond her school community. This demonstrates that Tracy's lack of social resources was compensated for by different social resources that were mostly available outside of the school. Such relationships were considered one of the interactions documented and presented in the Findings section.

Focal Episode Selections and Constructing a Case

Once the coding was complete, we looked for stories that showed Tracy's CRT resource activation of critical data literacy. For each episode thread, we identified subthemes, grouped the episodes according to those subthemes, and constructed a final case. While purposely selecting focal episodes, our aim was not to identify an exceptional or isolated representation. Rather, we aimed to use a clear exemplary case to theorize about characteristics that likely existed across our data set. In addition, we shared the chosen episodes with Tracy as a form of member-checking. As well as corroborating or correcting the narratives, Tracy had the opportunity "to theorize about [her] own professional practice as [she] attempt[ed] to improve the quality of [her] own and others' learning" (Dhunpath, 2000, p. 544). During this process, we noted themes that were central to the impact of PD on Tracy's resource activation. Finally, through peer review, we further refined our theoretical lens, analysis, and narratives. In this way, analysis was an interactive process involving continual adding, deleting, modifying, merging, and subdividing categories depending on the requirements emerging from the coding: emerging themes were compared with the empirical evidence as a theory began to be developed.

Table 2
Coding Manual for Resource Activation

Category	Definition	Examples
Material resources	Learning supplies such as textbooks, data collection devices, computers, and consumable equipment.	**Material Resource Activation.** The teacher was not able to demonstrate correcting a bar graph when multiple students asked for help so she located a student handout provided from the summer PD and pointed to the steps that students could follow (*Here the inference is that although the teacher did not appear to be proficient with data analysis tools, she was able to find the proper material at hand*).
Cultural resources	Teachers' conceptual understanding of data literacy; teachers' pedagogical strategies to foster critical data literacy and/or school's preferred instructional approach; students' knowledge, experience, language, and academic abilities; and the culture of the school.	**Cultural Resource Activation.** Tracy had a very clear understanding of how she would like to introduce the PBL to students to support content knowledge. She used local and personal examples when introducing the problem of asthma and air quality to students. Tracy also placed more of an emphasis on socio-ecojustice than on learning bioinformatics content throughout the implementation of her lesson plan. (*Here the inference is that she was able to contextualize learning in ways that are relevant and meaningful to students*). **Cultural Resource Activation to Revise Material Resources.** One of the biggest challenges for Tracy was finding out the best ways to introduce air quality sensors and an app to students along different developmental paths so that they would individually have sufficient understanding of using technology to complete the data collection activity. Thus, she revisited the PD materials, replaced some of the steps, and broke them down into smaller steps. (*Here the inference is that the teacher activated cultural resources by revising the materials to support student learning as she anticipated that her students would get frustrated with using technology. The teacher utilized PD resources to meet her pedagogical goals).*

Table 2 (Continued)

Category	Definition	Examples
Social resources	Opportunities for teachers to develop trust, friendship, and agency with other teachers and administrators.	**Social Resource Activation.** Tracy requested the research team's support at both the planning and revision stages. The research team also visited the teacher's class to provide onsite support during classroom implementations. (*Here the inference is that the teacher used the support of the research team to develop instructional materials that helped her with lesson planning*). **Social Resource Activation to Complement Cultural Resources.** During the workshop sessions, teachers shared their experiences of working with the sensors such as any unexpected occurrences or challenges during data collection activities. In the next class, Tracy simplified a student handout that was originally seven pages long into one-and-a-half pages. *(Here the inference is that Tracy activated social resources by utilizing the workshops as an opportunity to seek and receive support in envisioning data literacy activity implementation and preparing for anticipated challenges).*
Symbolic resources	Institutional social value that is ascribed to different forms of instruction; whether and how data literacy in different content domains is prioritized; and recognition of teachers' efforts to integrate data literacy into their existing curricula.	**Symbolic Resource Activation.** During the interview, Tracy mentioned that the school principal showed great interest in her work from the PD and that they allowed her full autonomy to bring a new curriculum to her class. (*Here the inference is that the teacher had symbolic support to pursue a more innovative approach to science teaching*).

Findings

Throughout the study, Tracy activated all four resource types for the implementation of her curriculum. Notably, she exhibited proficiency in harnessing cultural and material resources, whereas her activation of social and symbolic resources was less pronounced. In this paper, we highlight the cultural and social resource activations that were notable for opening up access to other resources that were not readily available for the implementation of the bioinformatics PBL curriculum.

Examination of Resource Activation and its Prominence in CRT Support

To respond to research question 1 ("How does Tracy's resource activation contribute to supporting CRT in the curriculum, and which types are most and least prominent?") the data sources were coded to understand how Tracy activated resources in each category and how these activations opened up opportunities to activate other resources for implementation. Our analysis shows that cultural resources were the resources most commonly activated (42%), followed by material resources (28%). Activation of both social resources and symbolic resources was observed to occur to equal extents (15% each). The lower number of social resource activations indicates that there were comparatively fewer opportunities to activate social resources (e.g., by connecting with other experts within the school to enhance her teaching practices for data literacy).

In Tracy's case, the activation of cultural and social resources not only created opportunities to overcome constraints but also played a significant role in her teaching approach. In the next section, along with the response to research question 2 ("In what ways do different types of resource activation relate to each other in order to effectively support CRT in the curriculum?"), we provide evidence of and detailed insights into instances of activating cultural and social resources, thereby accessing various types of resources. Here, we present a brief overview of the instances. While the activation of cultural resources was the most prevalent form of resource activation, notable interactions between material and cultural resources emerged throughout the study. Expanding on the foundation of cultural resources, Tracy revised the curriculum materials to be more comprehensive and responsive to her students' learning needs, which explains why material resources received the second-highest number of codes. Moreover, it is important to note that Tracy frequently leveraged social resources to bridge gaps in her existing network, such as when she lacked access to other science teachers within her school for collaborative curriculum development and teaching.

Integrative Dynamics of Resource Activations

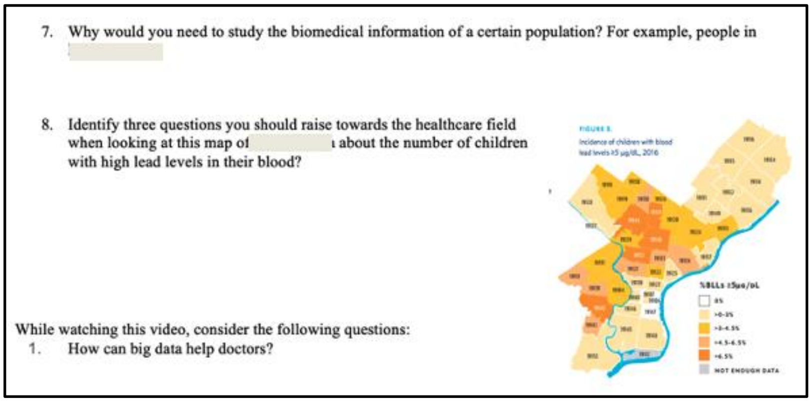
Contextualizing Instruction through Cultural Resource Activation: Bridging Curriculum Gaps

One of the notable ways in which Tracy activated cultural resources was by using contemporary examples from the local community, thus making curricular content more relatable. In making these changes to classroom materials (material resources), Tracy took the time to carefully consider her student population and what would be feasible and appropriate for them (cultural resources). For example, in response to her students' understanding of the project, Tracy introduced a new set of examples, incorporating contemporary scientific issues and recent events. To illustrate the relationship between the environment and health, Tracy added questions with a heat map of the city showing the incidence of children with blood lead levels (Figure 5).

With that image, Tracy initiated a discussion about the locations in the city where lead cases were found and the possible causes. During this activity, students engaged in a conversation about the significance of studying bioinformatics research, particularly focusing on asthma and air quality research within the African American population. Additionally, students formulated three questions related to the healthcare field based on the city's heat map, which indicated the number of children with high levels of lead in their blood. This exercise aimed to generate research questions for their asthma and air quality project. During an interview, Tracy explained the rationale behind this adjustment, stating, "[W]e were looking for some kind of correlation. I thought it would be really beneficial for the students because they are from [City]. They can see the area they live in and analyze it." Tracy clearly aimed to incorporate cultural relevance into the science classroom to foster student engagement and learning. By connecting science to students' daily lives and using community-relevant examples, Tracy activated cultural resources to encourage inquiry and discussion.

Figure 5

Screenshot of the Student Handout with Prompts



7. Why would you need to study the biomedical information of a certain population? For example, people in

8. Identify three questions you should raise towards the healthcare field when looking at this map of ı about the number of children with high lead levels in their blood?

While watching this video, consider the following questions:

1. How can big data help doctors?

Another common way in which Tracy activated cultural resources was by using examples from recent news articles to address the complex variables that could impact air quality. One of these news articles detailed an explosion that occurred in an oil refinery located in the southern part of the city. The explosion took place six months before the lesson and, as a result of it, the oil company had gone out of business. In the interview, she said,

> I talked about that and used it as an example and so many kids actually remember that example. And so, we start talking about, well what do you think that did to the air quality for people who lived in that area? How did that affect them? And what type of people live in that area? Stuff like that.

Tracy used a recent news event to make the topic more relevant to students. By incorporating contemporary, real-world examples, Tracy expanded the context of students' learning beyond the classroom and connected it to their families, friends, and the places they live. Furthermore, learning the content within a context that was pertinent to their lives proved to be beneficial for students. In her interview, Tracy further expressed a clear goal to enable students to personally connect with community issues and apply scientific problem-solving skills, stating, "I wanted to bring in that real-world information and make something that doesn't seem realistic, realistic because they already know it happened. Perhaps many of the kids even live near [the incident]."

She similarly incorporated personally relevant, local, and timely examples when introducing the problem of asthma and air quality to students. She also found that using news from the community proved helpful in situating the problem within students' existing knowledge. These examples show that Tracy's implicit understanding of the content levels required for student learning (cultural resources) motivated her to examine and modify the teaching materials accordingly. Throughout the curriculum implementation, Tracy utilized her cultural resources to contextualize the instruction and curriculum materials for students, filling in any gaps that existed. Tracy's abundant cultural resources and her activation of them played a significant role in revising curriculum materials.

Navigating Social Resources Beyond the In-School Network to Access Expertise

Our analysis showed that most social resources were activated when Tracy tried to overcome gaps in existing social resources within her school. These gaps included insufficient support to address technical issues such as unstable Wi-Fi connections, and Tracy's lack of access to other science teachers with whom to collaboratively develop and teach the curriculum. When the research team inquired if there were any other teachers in the school interested in collaborating, Tracy responded by saying "no" and explaining that she was the only biology teacher in her school, while also teaching ES. She then shared her implementation plan:

> I teach ES too, because they necessarily didn't have ES, when they were in the ES, one class, if that makes sense. So basically, we're trying to prepare students for the Keystone exam. And the idea is that in ES, they take, they put their time going through the first half of the content for biology. And then when it comes to me, I can review the first half and then take my time going through the second half of content, just so that we have more time to do labs and experiments and support them to pass the exam. So, they're not really introduced to ES until they come to me for ES, too.

As explained in the above quote, there was another science teacher who taught ES, but the class primarily focused on introductory-level biology, which was dedicated to preparing students for the state standardized exams. To accommodate this, the ES class was divided into two halves. In the first half, students learned biology content; in the second half, they focused on ES to allocate more time for test preparation in biology and improve their performance. During the post-implementation interview, Tracy also explained that "There's only, what, 12 teachers there," and further clarified that in her school, "there are two other science teachers. One teaches ES and one class of chemistry, and the other teaches chemistry and anatomy and physiology." Despite having two other science teachers in the school (out of a total of 12 teachers), Tracy was the only one implementing the bioinformatics PBL curriculum and integrating data literacy into science classes. This indicates that she did not have access to other expert teachers in her school who were familiar with the content knowledge of the lessons and activities. Similarly, when asked if she had discussed the project with anyone else, Tracy firmly answered, "no," and explained, "I don't know many teachers, well... My friends are elementary school teachers, so I know a lot of them, but I don't know many high school teachers." This quote highlights her limited access to other high school science teachers within her professional network with whom she could connect, share her work, and reflect on the curriculum implementation.

Despite the lack of social resources within the school community, Tracy was able to leverage resources beyond it. Tracy primarily activated these social resources through her participation in Saturday PD workshops throughout the school year. These workshops invited science teachers who were preparing or implementing PBL curriculum and provided a platform for them to share experiences and strategies that were successful or challenges they encountered during the curriculum implementation. While the research team facilitated the workshops, the discussions were led by the participating teachers. Tracy made time to attend these workshops as they presented an opportunity for her to collaborate with other science teachers in the cohort. For example, during one of the Saturday PD workshops, the research team prompted teachers to share their experiences with working with the sensors. When the discussion began, Luke, a biology teacher who had taught up to the lesson introducing the air quality sensors and app, turned to Sam, another biology teacher who had completed the outdoor data collection activity, and asked if there were any unexpected occurrences or unanticipated challenges during the outdoor data collection. Sam shared his experience of technical glitches that arose during his class, resulting in his students returning on another day to collect more data. He said:

> For the most part, it went pretty well with the outdoor data collection. I had them make sure that they were uploading at least one data point while they're still in the classroom. I went over the norms. And then I just kind of broke it down into basically like three or four steps that are that way. It's like, make sure you hit save, when you come back into [the] building, you hit Upload.

He emphasized the importance of ensuring that students' test data was uploaded to the Google Sheet before leaving the class. Sam also mentioned simplifying the steps into three or four concise instructions to make them easier for students to remember. This discussion was significant because Tracy incorporated some of the ideas and strategies shared during the conversation into her own implementation of the lesson. Tracy utilized social resources from the PD to complement her activation of cultural and material resources. For example, Tracy reminded the entire class to test their devices and ensure proper data uploading before leaving the classroom. On the second day of introducing the sensors, she stated, "All right, so we upload our data and then go back to the classroom to see if it comes through. Can everyone see their data? Can everyone do a 'live data upload'? You didn't do a live data upload?" (12/11/2019). Prompted by her instructions, the students checked whether their data had been uploaded correctly.

On another day, Tracy explicitly explained the importance of uploading data and provided instructions on how to do it. After receiving multiple reminders from Tracy and participating in whole-class practices using sensors, the students independently tested the sensors before leaving the class to ensure they functioned properly while collecting data. For example, they would remind each other, "Make sure you save it a couple of times" (12/19/19). In addition, based on Sam's suggestion, Tracy developed a simplified version of the steps that her students would find more accessible to her students. Likewise, Tracy utilized Saturday PD workshops as an opportunity to seek and receive support in envisioning the implementation of data literacy activities and preparing for anticipated challenges.

Participating in the PD workshops allowed Tracy to leverage social resources to acquire material and cultural resources for teaching the curriculum.

Discussions

This study sought to better understand how the activation of resources can support CRT for STEM, specifically critical data literacy. As the world increasingly relies on data-driven decision-making, the role of critical data literacy within our educational system becomes ever more paramount. As a response to promoting learning about data in high school classrooms (Carlson et al., 2011; Ganesan & Leong, 2020; Gebre, 2018; Johnson et al., 2016; NGSS Lead States, 2013), the bioinformatics PBL curriculum aims to provide students and teachers with opportunities to investigate local contexts and encourage students to utilize their personal experiences to establish meaningful inquiry (Erickson, & Gutierrez, 2002; Kovarik et al., 2013; Mensah, 2022; Philip et al., 2016). By leveraging cultural resources, Tracy revised the curriculum materials to be more comprehensive and responsive to students' learning needs. This approach, characterized by its responsiveness to student backgrounds and experiences, allowed her to make the bioinformatics content more relevant, accessible, and engaging, thereby enhancing the overall effectiveness of her instruction. Tracy's teaching aligns with existing research on CRT, which emphasizes the importance of teachers adapting instructional materials to better suit their students' cultural backgrounds and learning needs (Gay, 2002; Ladson-Billings, 1995). By doing so, teachers can create more engaging and meaningful learning experiences, which can ultimately improve students' academic outcomes (Gutiérrez & Johnson, 2017; Rivera Maulucci, 2010). Furthermore, Tracy's teaching exemplifies the necessity of teachers to not only understand their students' cultures but to also using that understanding to inform their teaching practices (Barron et al., 2021; Erickson, & Gutierrez, 2002).

Tracy's strategic use of social resources beyond the school community was crucial in overcoming limitations to access additional support. Through external social resources, such as the PD workshops and collaborations with the research team, Tracy gained new insights and adapted her perspective on the importance of CRT. Studies have found that teachers with robust professional networks are more likely to adopt innovative teaching practices, including CRT, because they have access to a broader range of ideas, resources, and support (Yoon et al., 2017; Grossman & Thompson, 2008; Luft et al., 2015). By highlighting the significance of external networks, our study suggests that there are benefits to a broader, more integrated approach to teacher development in CRT for critical data literacy, which can be instrumental for educators who may lack substantial internal institutional support. Furthermore, Tracy's ability to pivot between different types of resources when faced with limitations showcases how important it is for teachers implementing STEM curricula to realize that additional resources can be activated by the ones they have more readily available. This adaptivity in resource activation, particularly in the context of CRT, is a key takeaway from our research. It marks the importance of collaborative problem-solving in educational settings, especially when implementing new and challenging STEM curricula like bioinformatics.

In terms of the broader research landscape, this study contributes to our understanding of resource activation in the context of implementing a culturally relevant and critical data literacy curriculum. While previous research has primarily focused on individual types of resources (Diamond et al., 2014; Fischer et al., 2018; Johnson, 2011), our analysis uniquely explores the dynamic interplay and interdependencies between various resources. This holistic view offers a more nuanced understanding of how teachers like Tracy navigate and leverage these resources in real-time, adding a vital dimension to the literature on resource activation in education. Furthermore, unlike studies that often limit their scope to the examination of teachers only in light of an intervention or lessons (Johnson, 2011), our study adopts a broader perspective. We observed Tracy's resource activation not only during class implementation but also in her preparatory and reflective phases. This comprehensive approach reveals how teachers strategically activate different resources across various stages of their instructional practices, highlighting the presence of a continuous, adaptive process rather than isolated instances of resource use.

Our findings can inform future studies, particularly by providing a novel lens through which the interconnectedness of different resource types can be examined. This approach encourages a more comprehensive evaluation of the resources activated by teachers, moving beyond the traditional emphasis on material and immediate classroom resources to include a broader range of supports. This perspective can usefully inform future studies, particularly those aiming to understand the complexities of integrating innovative pedagogies in diverse educational settings. Therefore, one of the implications of this research is that it offers insights into the multifaceted challenges teachers face as they implement an integrated STEM curriculum, such as the bioinformatics PBL curriculum, in science education. By examining how these resources were activated and their salience, this study provides insights into the challenges and opportunities teachers face in integrating critical data literacy in their teaching.

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Appendix
Appendix A

K-12 Bioinformatics Lesson Scope and Sequence

Lesson Number	Title
Lesson 1	Introduction to Project
Lesson 2	Introduction to Bioinformatics
Lesson 3	Introduction to Analyzing Data
Lesson 4	Interpreting Results
Lesson 5	Introduction to the Exploratory Data Analysis Tool
Lesson 6	Using the Exploratory Data Analysis Tool to Develop Inferences
Lesson 7	Introduction to Genotype and Phenotype
Lesson 8	Comparing Continuous Variables
Lesson 9	The Exposome
Lesson 10	Introduction to Measuring Air Quality
Lesson 11	Data Collection Part 1 - Around the School
Lesson 12	Planning Your Investigation - Part 1
Lesson 13	Web Research on Environmental Action
Lesson 14	Planning Your Investigation - Part 2
Lesson 15	Data Collection Part 2 - Out in the Neighborhood
Lesson 16	Data Analysis and Visualization
Lesson 17	Developing the Project Report
Lesson 18	Class Presentations

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