ABSTRACT

As computer science (CS) education becomes more prevalent in K-12 instruction, it is critical for educators, researchers, and curriculum developers to identify culturally responsive and pedagogically inclusive approaches that can increase participation, access, and feelings of belonging for students from historically marginalized communities. In response, we developed an equity-centered curricular framework and illustrative crosswalk that synchronizes three distinct pedagogical approaches: culturally responsive pedagogy (CRP), Universal Design for Learning (UDL), and project-based learning (PBL). We describe the framework’s theoretical underpinnings and explain how this framework informed the development of an integrated elementary science+CS curricular unit and provide examples of its implementation. Next, we describe the relationship between our framework, the integrated curricular unit, and educative materials designed to help teachers use the lessons and transform their practice. Finally, we highlight the framework’s potential for broader implementation in the quest to promote equitable CS instruction grounded in the experiences and perspectives of diverse student populations. The crosswalk is a graphical representation of the framework that communicates relationships amongst the elements in a digestible and practical way. This Equity-Centered Curricular Crosswalk addresses both lesson features and teacher practices, to underscore our belief that the responsibility of equity-based pedagogy should not be solely borne by teachers. As educators, researchers, and curriculum developers consider their interconnected roles and responsibilities in the enactment of CRP and UDL, the crosswalk provides an important link between equity-based instructional theories and the realities of classroom practices.
1. INTRODUCTION

As Computer Science (CS) education becomes increasingly au courant in K-12 curricula, elementary teachers have been called upon to teach their students CS or computational thinking (CT), often with little knowledge of either (Ozturk, Dooley, & Welch, 2018). This expectation often requires teachers to integrate CT and CS content across the traditional curriculum while considering the needs of all learners (Israel et al., 2015). While CS is a discipline that goes beyond CT, hereafter our focus will be on CS instruction (Voogt et al., 2015). Given the incredible demands on teachers, it is critical for CS educators, researchers, and curriculum developers to carefully consider how best to design curriculum and equip in-service teachers to implement CS instruction using inclusive approaches that can increase participation, access, and feelings of belonging for students from underrepresented and historically marginalized communities. In service of this goal, we developed an equity-centered curricular framework and illustrative crosswalk that orchestrates principles of project-based learning (PBL), Universal Design for Learning (UDL), and Culturally Responsive Pedagogy (CRP). The purpose of this framework is to support teachers in providing high-quality and equitable CS instruction for diverse student populations. The illustrative crosswalk distills the pedagogical approaches into a list of equitable teacher practices and lesson features that can be directly applied to classroom practice and curriculum. We present this equity-centered framework alongside an integrated curricular unit in order to demonstrate its utility and provide a tangible example of how it can be used to transform pre-existing curriculum and instruction.

2. CONTEXT

CS is ubiquitous in our modern society, but access to CS education is more of a privilege than a commonality (Goode, Flapan, & Margolis, 2018). Enrollment in undergraduate Science and Engineering (S&E) programs is considerably lower among students from historically underrepresented groups. For instance, in 2018, among all US citizens and permanent residents, 57.9% of bachelor’s degrees in S&E were earned by Whites. Conversely, Asians earned 10.7%, Hispanics and Latinos 15.1%, Blacks or African Americans 8.5%, and American Indians or Alaska Natives 0.4% (National Center for Science and Engineering Statistics (NCSES), 2021). Fewer data are available on persons with disabilities categorized by field of study. However, the NCSES (2021) reported that in 2019, 9.1% of doctoral degrees were awarded to persons stating a disability. These statistics paint a sobering picture—the endpoint of the historical effects of our status quo STEM and CS education—and reveal a need to proactively design CS instruction that meets the needs of all learners.

Increasing awareness of CS education has been shown to positively impact middle and high school students (Grover, Pea, & Cooper 2016; Settle et al., 2012). Similarly, a growing body of research indicates that introducing CS concepts at younger grade levels improves language arts (Grover & Pea, 2018; Smith & Burrow, 2016), mathematical logic (Bers, 2019; Gadanidis, 2017; Rodriguez-Martinez, 2020), and creativity (Israel-Fishelson & Hershkovitz, 2022). However, elementary schools face challenges integrating CS concepts in traditional content areas (Umultu, 2021; Yadav, Stephenson, & Hong, 2017). Elementary teachers typically teach all content areas and prioritize literacy and math over other subjects such as social studies and science, commonly due to limited guidance on how to design curricula that integrate different areas (Ketelhut et al., 2020; McGinnis et al., 2020). Moreover, adding CS concepts to an already full curriculum requires practical frameworks and design principles to facilitate its integration into traditional instruction (Strickland et al., 2021). We cannot trivialize the burden elementary teachers shoulder as they are left to figure out how their teaching practice can satisfy all these needs. Frameworks may compel action, but teachers should be supported as they adapt their practice to push their current pedagogical limits in ways that balance the demands of their profession and benefit their students.

We engaged in this work within the context of a research-practice partnership (RPP) project funded by the National Science Foundation (NSF). The partnership comprises a large, diverse urban school district and two universities. This project was conceived as an effort to help teachers find time for high-quality science and computer science instruction in the elementary school day using a project-based learning (PBL) approach, which was already established in the school district. Within the district, approximately 50% of students are white, 40% are Black, 4% are Asian, 4% are multiracial, and less than 1% are Native American/Alaska Native or Native Hawaiian/Pacific Islander; approximately 40% are Hispanic. In addition to English, the three predominant languages spoken by families within the district are Haitian Kreyòl, Portuguese and Spanish. The school district partners helped identify four ‘partner teachers’ who contributed their perspective to the development of the equity-centered framework, reviewed and provided feedback on early drafts of the science+CS curriculum under development, and implemented a pilot version of the curriculum with their students. University partners led the curriculum development work, including the
creation of the equity-centered framework and crosswalk described herein, and conducted component-based research on the implementation of the new science+CS curriculum. Component-based research enables a focus on key questions that pertain to understanding not only what might work, but also what parts of it might work for whom, under what conditions (Century & Cassata, 2016).

The development work described here is not research and thus was not subject to IRB oversight; the larger overall project was reviewed and approved by IRBs at the partner universities and by the school district. As we considered the current social climate, classroom realities, and potential challenges related to our planned curricular intervention, we articulated another primary objective— to help teachers contextualize and transform their practice by integrating inclusive pedagogical approaches into their instruction. Therefore, we decided to synthesize PBL with two approaches that have been shown to promote inclusive learning in K-12 CS education: Universal Design for Learning (UDL) and culturally responsive pedagogy (CRP).

3. THEORETICAL FRAMEWORK
3.1. PROJECT-BASED LEARNING (PBL)
Over the past several decades, PBL has emerged as a common pedagogical approach in the K-12 CS curriculum (Chiu, 2020). PBL is an instructional method that actively engages students in solving a real-world problem or challenge or answering a complex question (Buck Institute for Education, 2019). As opposed to creating projects as one-off assignments, PBL requires an extended period of investigation and exploration culminating in the sharing of a final product with an audience (Yang et al., 2018). Students must venture beyond rote memorization to apply higher-order thinking skills such as problem-solving, collaboration, and creativity as they search for answers to driving questions and create quality products. Studies have shown that infusing PBL into CS instruction provides numerous benefits for learning, including helping learners connect different ideas and knowledge (Asunda, 2018), improving learners’ CS attitudes (Ulzii-Orshikh & Dougherty, 2020), enabling empowered learning through exploration (Chiu, 2020), and developing learners’ deep content knowledge (Buck Institute for Education, 2019). The Buck Institute for Education has developed a research-informed model consisting of essential project design elements meant to guide practitioners in applying PBL within their curriculum (Larmer, Mergendoller, & Boss, 2015). However, a recent review of the literature shows that limited frameworks exist to support PBL’s implementation (Saad & Zainudin, 2022).

3.2. UNIVERSAL DESIGN FOR LEARNING (UDL)
UDL is an inclusive approach to teaching and learning that provides every student with opportunities to succeed. UDL promotes removing barriers to learning in diverse classrooms through flexible, usable, and accessible instruction that addresses the unique strengths and learning needs of students with and without disabilities (Burgstahler, 2008; Rose, Meyer, & Hitchcock, 2005; Israel et al., 2020). The UDL framework was developed by the Center for Applied Special Technology (CAST), a nonprofit research and development organization that promotes the expansion of equitable learning opportunities. The framework includes three guiding principles: multiple means of engagement (the “why” of learning), multiple means of representation (the “what” of learning), and multiple means of expression (the “how”) of learning (CAST, 2018). Although recent studies have shown that UDL can increase participation and success in CS education for historically marginalized and underserved groups (Israel, Lash, & Ray, 2017; Ladner & Israel, 2016; Lechelt et al., 2018; Ray et al., 2018), research on UDL in CS education is still emerging.

3.3. CULTURALLY RESPONSIVE PEDAGOGY (CRP)
Increasing access to CS for all students has become a widespread goal in education, inciting a national initiative to provide underrepresented K-12 students an opportunity to participate in CS education (Madkins et al., 2019). In order to scaffold a diverse pathway for all students to participate in CS, researchers suggest that course content should be relevant to a student’s real-life experiences and interests (Margolis & Goode, 2016). Madkins, Howard, & Freed (2020) examine various equity pedagogies within the context of CS education, namely: culturally relevant pedagogy (Ladson-Billings, 1995; 2006); culturally responsive teaching (Gay, 2000); culturally sustaining pedagogy (Paris & Alim, 2017); and culturally responsive computing (Scott & White, 2013). More recently, the Kapor Center offered the Culturally Responsive-Sustaining CS Education Framework (Kapor Center, 2021), a framework for the design and implementation of culturally responsive-sustaining pedagogy in CS classrooms through courses of action which can be used to guide practitioners, curriculum developers, and policymakers in closing the equity gap in computer science education. These courses of action are driven by six core components: acknowledge racism in CS, create inclusive and equitable classroom cultures, implement rigorous curriculum and pedagogy, engage student voice, agency, and self-determination, involve family and community, and expose students to diverse CS/tech professionals as role models. In this paper and our CS-focused project work, we used the term ‘culturally
responsive pedagogy’ and the acronym ‘CRP’ as an aggregate of these equity pedagogies focused on culture, guided by the Kapor Center’s nascent work.

3.4. PROMOTING AN ASSET-BASED MINDSET IN OUR DEVELOPMENT WORK

Drawing from the Interconnected Model of Professional Growth (IMPG) proposed by Clarke and Hollingsworth (2002), we believe that teachers’ changes to their pedagogy are cyclic, involving several iterations of reflection and practice. In our adapted version of the IMG model (Figure 1), teacher professional growth is conceived as the non-linear interconnection of four domains through mediated processes of ‘reflection’ and ‘enactment.’ The educative materials and graphical representation of the framework –external domain– leverage the design development and implementation of inclusive CS instruction –the domain of practice– leverage the design development and implementation of inclusive CS instruction –the domain of practice– aiming to increase participation and access –the domain of consequence– facilitated by the inclusive mindsets –the personal domain. The personal domain is of particular interest in our work as we believe teachers’ knowledge, beliefs, and attitudes are a catalyst for implementing equity-based CS instruction. We conceptualize these in the form of five equity-oriented CS mindsets, which we argue are necessary for recognizing that all students belong in K-12 CS education. These mindsets are intended to guide educators in proactively applying our equity-centered curricular framework to their instruction, based on the notion that all students can achieve and deserve an opportunity to learn CS (Israel, 2021). The five equity-oriented CS mindsets described in (Israel et al., 2023) are as follows:

1. All learners deserve to be meaningfully included in CS education.
2. All learners can succeed in CS instruction.
3. Learner variability is an asset in the CS classroom.
4. CS instruction must engage all learners.
5. Advocating for CS instruction challenges barriers and opens pathways to participation.

4. DEVELOPING AN EQUITY-CENTERED CURRICULAR FRAMEWORK

4.1. SYNTHESIZING OUR FRAMEWORK

To guide the design and implementation of elementary science+CS curricular materials (the module), we developed an equity-centered framework that synthesized PBL, UDL, and CRP using the following resources: Buck Institute for Education’s PBLWorks Essential Project Design Elements (2019), Creative Technology Research Lab’s UDL in CS Remix Table (Israel et al., 2017), and the Kapor Center CRCS framework (2021). Figure 2 illustrates the outcome of our synthesis by highlighting the potential for eight PBL elements, three UDL principles, and five CRP guidelines to be flexibly aligned with one another, like metaphorical

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**Figure 1** The Interconnected Model of Professional Growth – Adapted version.
gears rotated around a shared axis—yielding various combinations that can guide equitable lesson design and teacher practice. Our new framework also emphasizes the five equity-oriented mindsets we believe to be necessary for successfully facilitating equitable CS instruction. We wish to note that our framework features only five of the six guidelines from the Kapor Center’s CRCS framework, as we felt that the additional guideline prioritizing student voice and agency was already synthesized as a crucial aspect of UDL theory.

4.2. AN EQUITY-CENTERED CURRICULAR CROSSWALK

Separately, the three approaches within our equity-centered framework rely on theoretical foundations that can be complex for teachers to balance and translate to practice (Israel et al., 2022). Furthermore, synchronizing these approaches is even harder at elementary levels, where most teachers are responsible for addressing a variety of content areas in their lesson design and instruction (Markworth et al., 2016). To address these concerns, we developed a curricular crosswalk that can support teachers’ equitable implementation of the science+CS module and provide curriculum developers with a digestible representation of the framework’s components. The crosswalk is a graphical representation of the framework that communicates relationships amongst the elements in a digestible and practical way. This Equity-Centered Curricular Crosswalk addresses both lesson features and teacher practices, to underscore our belief that the responsibility of equity-based pedagogy should not be solely borne by teachers. As educators, researchers, and curriculum developers consider their interconnected roles and responsibilities in the enactment of CRP and UDL, the crosswalk provides an important link between equity-based instructional theories and the realities of classroom practices.

We chose to anchor the crosswalk with the PBL project design elements, because these elements describe features and structures to be built into the design of a particular project, whereas UDL and CRP are holistic and integrative approaches to pedagogy. Using PBL as an anchor also enabled us to leverage the partner teachers’ relative familiarity with this instructional approach. We used the PBL elements to represent key elements within the science+CS module, while the UDL and CRP guidelines represent equitable teacher practices for implementing each element. Table 1 provides an excerpt from the crosswalk, while Appendix A features the crosswalk in its entirety. The first column consists of the design elements aligned with PBL, while the second and third columns identify equitable teacher practices aligned with UDL and CRP. A numbering convention identifies each equitable teaching practice with an alpha-numeric
The excerpt features two PBL elements: PBL4: Authenticity and PBL6: Reflection.

**Table 1** Excerpt from the Equity-Centered Curricular Crosswalk.

<table>
<thead>
<tr>
<th>PBL 4: AUTHENTICITY</th>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Help students identify impactful, real-world problems that are relevant or important to them.</td>
<td>• Use everyday examples to activate background knowledge. (4.UDL.a)</td>
<td>• Provide opportunities for students to take an active role in solving real-world problems that are meaningful to them. (4.CRP.a)</td>
</tr>
<tr>
<td>Support student collaboration in high-functioning teams.</td>
<td>• Ensure activities are based on ideas that students find important, interesting, or relatable. (4.UDL.b)</td>
<td>• Share your story with students. (4.CRP.b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Discuss professionals who represent marginalized groups. (4.CRP.c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Include relevant connections to sociopolitical issues related to the content. (4.CRP.d)</td>
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<td></td>
<td></td>
<td>• Provide opportunities for students to take a legitimate role in addressing a challenging problem. (4.CRP.e)</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>PBL 6: REFLECTION</th>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build in purposeful reflection time, and guide students in reflection on what and how they are learning, and on the project’s design and implementation. Provide rubrics and multiple methods for self-assessment.</td>
<td>• Acknowledge difficulty and frustration. (6.UDL.a)</td>
<td>• Provide opportunities for students to create artifacts to critically assess, report findings, and document additional questions or wonderings from a social standpoint. (6.CRP.a)</td>
</tr>
<tr>
<td></td>
<td>• Show authentic examples of persisting through difficult problems. (6.UDL.b)</td>
<td>• Provide opportunities for students to critically examine their own cultural roles within society and in the context of the problem or question. (6.CRP.b)</td>
</tr>
<tr>
<td></td>
<td>• Model strategies for persistence and help-seeking. (6.UDL.c)</td>
<td>• Have students reflect on their perspectives and potential biases. (6.CRP.c)</td>
</tr>
</tbody>
</table>

Table 1

tag (e.g., 4.CRP.c, 6.UDL.b), making it easier to reference them throughout the curriculum materials. We wish to note that although the crosswalk was designed to deliver a comprehensive list of proactive approaches for meeting the needs of all learners in the context of our elementary science+CS module, teachers are expected to identify and apply the most suitable practices according to the nature of their instruction across grade levels and subject domains. The excerpt features two PBL elements: PBL4: Authenticity and PBL 6: Reflection.

The crosswalk development process involved multiple design iterations informed by consistent discourse between the research team, curriculum developers, and partner teachers from the school district. The research team led the design effort to transform the framework into a usable and practical tool that communicated the relationships between PBL, UDL, and CRP in a digestible manner for teachers and curriculum designers. The curriculum development team provided consistent feedback along the way as they simultaneously developed the science+CS module, eliciting numerous revision cycles. The partner teachers also contributed useful insights during the design process that helped ensure the tool’s clarity and usability in classroom practice. Our diverse positionalities (i.e., professional and personal identities, backgrounds, and experiences), while a pronounced asset with respect to considering impact on the diverse community we sought to serve, sometimes prompted disagreements during the development process. When these instances occurred, all the teams met weekly to discuss differences and reach consensus in all aspects of the crosswalk’s development.

5. APPLYING THE FRAMEWORK TO CREATE EXAMPLE CURRICULUM

The project’s curriculum development team was tasked with concurrently developing an integrated elementary science+CS module for 4th grade (9–11 years old). These curriculum materials would prioritize equitable instruction for the school district’s diverse student population, integrate science content focused on invasive species, and adapt CS curriculum materials, designed for 4th graders, with which the school district was already familiar. To produce a first draft of the module, we thoroughly examined pre-existing curriculum materials that were favored by partner teachers in the school district, to determine what could be revised or adapted, and what would need to be created from scratch to satisfy our equity-focused goals. As we worked to develop both teacher- and student-facing materials, the Equity-Centered Curricular Crosswalk served as a valuable lodestone or touch point. While our goal was to design each lesson with these equity pedagogies at the forefront and embed the equitable teacher practices in the lesson activities themselves, we found it important to also explicitly draw teachers’ attention to these practices, so that they might both recognize and understand what is being done and why it is done in that way. Our partner teachers piloted the first draft of the science+CS module in their 4th grade classrooms and committed to a collaborative co-development process—providing regular feedback about their implementation that would inform revisions—to create a final version of the integrated science+CS module.
5.1. TARGETED REVISIONS TO STUDENT-FACING LESSON MATERIALS

Collaborating with our partner teachers and research team in an iterative process produced targeted revisions to our lesson drafts in order to be more responsive to the Equitable Teacher Practices articulated in the crosswalk. Here we present a selection of these revisions and discuss how they improved the lesson activities with respect to equity-focused strategies. Below, the Equitable Teacher Practices that we employed are identified with their alphanumeric tags (listed in Appendix A).

5.1.1. In a lesson where students research local invasive species, we identified student choice as an important element. The original version of the lesson encouraged students to select one or more local invasive species to research and to share with others. In our revisions, we pushed ourselves to consider structures that would support student choice not only in what they researched, but also in how they record and share that information with others (5.UDL.a). Instead of a single note-taking page, the lesson now includes three options for students, along with teacher notes about offering options for audio or video recording (5.UDL.b). These student-facing resources also serve as tools that students might use to self-monitor as they engage in independent or collaborative research (3.CRP.b, 5.UDL.d).

5.1.2. As curriculum writers, we regularly attempt to connect with what students might already know or wonder about a particular topic. This might come in the form of questions like What do you already know about...? What do you think you know about...? or What do you notice? What do you wonder? Inspired by both the crosswalk and suggestions from partner teachers and project advisors, we identified places where our questions could connect better to students’ identities, to their communities, or to their values. Some examples include: Who might care about invasive species? Why might awareness of invasive species be important to a community? What information/whose voices might be missing from this data? (4.CRP.d, 2.CRP.a).

5.1.3. In a lesson that prompted students to create a project that represented themselves and communicated information they knew about invasive species, we first simply outlined the specifications of the project and encouraged teachers to co-create examples with the class. Revisions included finding and providing students with authentic #SciComm examples on social media, by a diverse group of professional and amateur scientists, and in languages other than English. Since students’ identity played such a key role in the planning and expression of their projects, we pushed ourselves to include examples that included a range of home languages that were popular in the district (e.g. Spanish, Portuguese, Haitian Kreyòl). We also hoped that this would make it easier for students to share the (often humorous) example videos with their families and imagine science communication as an activity that could take place within their communities (4.CRP.c, 1.CRP.a).

5.1.4. Our first drafts of homework in the module required students to do work at home and bring it back to contribute to the following lesson. Our partner teachers raised concerns about the potential to slow progress through the module and expressed misgivings about families’ access to the technology and resources needed to support students to complete this work with such a tight turnaround. We responded by shifting this approach to provide “Home Link Choice Boards” offered in each collection of four lessons. Home Link Choice Boards consist of nine activity suggestions (arranged in a $3 \times 3$ array), each of which invites students to interact with someone they know around related science and/or CS content. One major difference between this structure and traditional homework is the way that this offers choices to students and their families - both in the content and in the different ways they might engage in the work. Engaging families and recognizing the value they bring to the learning experience is the fifth core component of the CRCS framework. The revised Home Link Choice Boards provided teachers with one clear opportunity to utilize this practice (1.CRP.a; 5.CRP.a), thereby addressing their concerns about the unwieldiness of family involvement.

5.2. EDUCATIVE TEACHER-FACING MATERIALS

Our project design included the creation of educative online resources to support teachers in effectively planning and implementing the equity-focused, integrated science+CS module. These resources are an important link between the more general equitable teacher practices in the Equity-Centered Curricular Crosswalk and the specificity of the individual lesson plans in the modules, particularly for implementing teachers who would not closely collaborate with us as the partner teachers did. Educative materials included videos and explicit connections within the lesson plans. Videos not only included introductions to the lessons and the Equity-Centered Curricular Crosswalk, but they also emphasized the explicit connections between the PBL elements and the equity practices in the lessons and used specific examples to illustrate these connections to the lesson activities. Similarly, we used common visual cues and iconography among the Equity-Centered Curricular Crosswalk,
the videos, and the lesson plans. These educative materials were designed to add clarity and foundational background knowledge that teachers could use independently, thereby addressing a range of implementation barriers as described by Erkmen (1999)—first-order barriers (e.g., lack of equity-focused CS education resources tied to instruction) as well as second-order barriers (e.g., addressing fundamental teacher beliefs about equity in project-based CS instruction).

5.3. EXAMPLE INTEGRATED SCIENCE+CS LESSONS

To illustrate the potential of our integrated framework to transform instruction, we provide two examples of lessons from our integrated science+CS Module. The full 20-lesson module was written for fourth grade students (ages 9–11) and consists of 8 Science-focused lessons, 8 CS-focused lessons, and 4 lessons providing dedicated time for students to design and implement their final projects. Each lesson plan is written as a teacher-facing document, with an opener that includes Learning Goals, Preparation Tips, relevant Links, Vocabulary, and a specially written Equity Spotlight that summarizes the equity-based principles (UDL and CRP) of the lesson. The Teacher Guide (lesson plan) contains instructions for coordinating the Warm Up, Main Activity, and Wrap Up activities, with an expectation that the lesson may take approximately 50 minutes. The Teacher Guide is also embedded with the alphanumeric tags identifying the Equitable Teacher Practices from the Crosswalk (Appendix A).

5.3.1. Lesson 8: SciComm and Me

SciComm and Me is the fourth of the CS-focused lessons. Students use a block-based coding environment to create an interactive computer program (mini-project) that expresses who they are with text and custom images. They warm up for this coding activity by considering what key information they can communicate about invasive species and learn about SciComm (science communication) enthusiasts and professionals. For each activity, we provide teachers and students examples of SciComm videos and coded Sprite Lab projects to stoke their interest and engagement (1.CRP.a). The set of video examples purposefully includes multiple languages that are common in our partner school district (e.g. Spanish, Portuguese), employ popular social media platforms and formats (e.g. TikTok, YouTube), and feature people of various ages, races, and genders (4.CRP.c). Teachers are advised to choose amongst these video examples to provide students with multiple options that would suit the needs and interests of the students in their classroom. No new science content is explicitly taught, but each SciComm video features content or species that may be new to students.

The CS content of the lesson includes a focus on sequential thinking and conditional logic. Students assemble blocks of code that create different characters and objects on the screen and make them interact or move in a pre-set sequence or in response to user input. This coding work is scaffolded by using puzzles that progress to create an example ‘About Me’ interactive poster for a character, Rikki. As they move through the puzzles, they encounter more and more code blocks used to have Rikki share information about herself and her hobbies. Students are also given the opportunity to inspect an inspiration project that presents science information like the example SciComm videos but uses similar blocks to the Rikki puzzles. Students then have the choice to demonstrate their learning by using the ‘sandbox’ level to code a mini-project that could remix any of the code they worked on in this lesson. The subject of the project could be SciComm or an About Me poster (5.UDL.a).

Figure 3 shows the Equity Spotlight and the collection of Equitable Teacher Practices tags we highlighted in this lesson. The Equity Spotlight reads as follows, “In this lesson, students consider their own expertise (science facts they already know) and how it may help the people they know. They imagine a real-world situation where their expertise may add value and learn about amateurs and professionals who communicate science information to inform the public.” The Warm Up activity clears the way for students to retrieve information they already know about invasive species and experiences that may be familiar and authentic. The ‘Mad Libs’-style warm up has teachers soliciting this information from the class and positions students as the expert in the situation (2.CRP.b) and identifies their agency and value to their communities (4.CRP.d). From this perspective they are then able to consider their potential as amateur SciCommers as they watch the example videos. By using authentic videos sourced from social media, we create the opportunity for students to think about people they already know who communicate to others about science. This grounding sets students up to take a legitimate role in addressing a challenging problem (4.CRP.e) and a means by which to start doing so—coding a project to communicate science information about an invasive species.

5.3.2. Lesson 9: Communicating with Comics

Communicating with Comics is the fifth science-focused lesson in the module, immediately following the SciComm and Me lesson. In this lesson, students learn and communicate about ways that species move (or are moved) from their native habitat to a place where they are considered invasive. They warm up for this lesson by surfacing their own ideas either from previous lessons or everyday experiences (1.UDL.b) about how different types of organisms might move from one continent to another and what might happen when they arrive. The use of the Think-Pair-Share cognitive routine (Lyman, 1981) during this Warm
Up ensures that all students have a chance to participate. Routines like this can help support inclusive practices and develop student agency in the classroom. In the main part of the lesson, students have the opportunity to first move around the classroom to read comic strips that illustrate the movement of invasive species and to discuss what they see, think and wonder with a small group. They then have time to research the movement of an invasive species of their choice and create their own comic to illustrate how it moved or was moved from one place to another. Comics were chosen as a means of communication for several reasons. Graphic novels and comics are increasingly popular among students and tend to be naturally engaging—using informal language, colorful illustrations, and interesting ways of showing movement or sound.

Figure 4 shows the Equity Spotlight and the collection of Equitable Teacher Practices tags for this lesson. The Equity Spotlight reads, “In this lesson, students will represent their knowledge and understanding in various ways and will share their perspectives with one another by engaging in collaborative inquiry to research how an invasive species of their choice moved or was moved to a new location.” Comics, as a less traditional format of communication, might offer students a novel way to gather and process information, as well as many choices (e.g., digital or non-digital format, characters, etc.) as they design their own comics. Comics also present the opportunity to consider the movement of invasive species from multiple perspectives (6.CRP.c), perhaps those of both people and animals and those intentionally or unintentionally involved.

Figure 3 Equity Spotlight and Equitable Teacher Practices tags for Lesson 8: SciComm and Me.

Figure 4 Equity Spotlight and Equitable Teacher Practices tags for Lesson 9: Communicating with Comics.
While the lesson focuses primarily on the ways invasive species move from one place to another, students are encouraged to add other ideas to their comics as part of a Home Link Choice Board. This lesson connects in meaningful ways to the “Need to Know” questions students developed and track over the course of the module, asking them to reflect on their new learning and providing opportunities to ask new questions. Students also connect this learning to their final projects as they consider ways that a comic might be turned into a computer program.

6. DISCUSSION

6.1. SYNERGIES AND TENSIONS

In her seminal 1995 work, Ladson-Billings makes the case for the specificity of culturally relevant pedagogy, taking care to address the notion that it’s “just good teaching.” Such notions may serve to trivialize the specificity of a theory, dampening its potential impact and benefit to African-American students (Ladson-Billings 1995). Even as we iteratively constructed the crosswalk, attempting to provide teachers with practical guidelines and a common language across the distinct equity-focused approaches, we exercised great care to avoid compromising the specificity and integrity of each approach. At stake was not just the uniqueness or recognizability of the individual approaches, but also their potential to effectively address specific student needs. For example, the Kapor Center’s CRCS framework, which was released during the course of our study, unflinchingly addresses racism, and the need for enacting anti-racist practices. While we could connect these ideas to the PBL elements of Authenticity (PBL 4) and Reflection (PBL 6), we do not have an explicit mention of race in our synchronized crosswalk. Our equitable teacher practices instead make mention of ‘marginalized groups,’ ‘culture,’ and ‘sociopolitical issues.’ It remains an open question whether uneven emphasis could compromise the integrity of a single framework.

We wanted our partner teachers to be equipped to not just understand the theories but identify the ways in which they related to their current practice, and the changes they could make to better serve the needs of their students. Our curriculum developers, informed by their decades of classroom experience and work with teachers, carefully considered the potential pitfall of teachers’ tendency to absorb or assimilate new things into their existing practice, rather than confronting the distinction between the new idea and their previous practice. When teachers are instructed or encouraged to change the way they teach, they make sense of and respond to these shifts in a variety of ways. In a study of teachers’ responses to policy shifts in reading, Coburn (2004) found that the most common response (49%) was assimilation, or interpreting the message in a way that adapts it to fit with their prior beliefs or practices. Twenty-nine percent of responses involved rejection, or not changing anything about their classroom practice. Several factors impact teachers’ responses including how congruent the message is with teachers’ prior beliefs, how much they are supported by colleagues and professional development, and how voluntary or involuntary they perceive their engagement in such shifts. We remain mindful that teachers encountering our work would have current teaching practices both congruent and incongruent with equity-based pedagogies.

6.2. IMPLICATIONS FOR TEACHER PRACTICE

Is it possible to change teacher actions toward more equitable teaching practices without necessarily first changing their beliefs? We earlier discussed the IMPG model, which shows the cyclical, rather than linear process of teachers’ changes to their classroom practice. Even as we worked on developing high-quality curriculum to enact these equitable approaches (i.e., external domain in IMPG), we acknowledged that a curriculum on its own cannot force implementation of UDL and CRP in classrooms (i.e., domain of practice in IMPG). So much depends on teachers’ mindsets (i.e., personal domain in IMPG), how they situate themselves in the classroom, the ways in which they get to know their students, and the relationships they build. Approaches designed to broaden participation and focus on equity (i.e., UDL and CRP) must be robust enough to surmount the implementation barriers teachers face. Ideally, we want all students to be taught in a manner that is personally relevant and addresses their needs. However, given the perpetual inequity in science and CS education, this type of instruction is not the norm. Multiple reasons exist for this lack of focus on equity and access. Ertmer (1999) offers a frame for understanding barriers to implementing change as first-order barriers (i.e., those outside the control of the teacher such as lack of resources that promote inclusive approaches) and second-order barriers (i.e., those intrinsic to the teacher, rooted in their beliefs and experiences, such as whether they value inclusion and equity and their knowledge of inclusive, equity-focused instruction). And what of teachers who may be unwilling or do not recognize the need for change? The teacher resistance literature (e.g., Neri, Lozano, & Gomez, 2019) similarly situates resistance as both individual and organizational. The relationship between individual resistance and organizational factors may either contribute to that resistance or help teachers improve their practice. Given this literature, we wanted our work to address both first-order barriers (e.g., teachers’ biases about who can be successful and belongs in CS) and second-order barriers (e.g., lack of robust and educative teacher resources or curriculum focused on inclusive practices).
6.3. IMPLICATIONS FOR CURRICULUM

Ball and Cohen (1996) acknowledge the power of curriculum materials as “agents of instructional improvement.” Davis and Krajcik (2005) further explicate a set of design heuristics for “educative” curriculum materials “that are intended to promote teacher learning.” Accordingly, our project clearly intended to fully develop and test lesson plans, student-facing materials, assessments, and educative online resources for teachers to effectively plan and implement these materials. Curriculum can often be static – designed to assess and meet the needs of the so-called average student (Gavin et al., 2009; Gickling & Thompson, 1985). We wanted to create something that was fundamentally different – something that offered authenticity and choice to students, and helped teachers realize both how and why to do things differently. Identifying the relationships, connections, or synergies between PBL, UDL, and CRP was part of our curriculum team’s high-level planning very early in the project. As detailed in section 5, the crosswalk (as a tool) was being developed and iterated at the same time as the lessons were drafted.

The curricular materials are intended to support teachers in teaching authentically using both the UDL and CRP frameworks to teach in a more equity-focused manner, thus allowing our overall study to move beyond a focus on what works, to also consider what works for whom, under what conditions. As curriculum developers, questions we continually asked ourselves included:

If we want the teachers who use this curriculum to enact these equitable teacher practices, what does our curriculum need to provide?

What curricular structures or supports might embed these practices into the lessons in ways that they cannot be ignored, and in ways that potentially lighten the heavy lift of CRP and UDL?

While our integrated science+CS module does not definitively answer these questions, it is meant to provide examples of curricular structures that will support teachers in their efforts to use UDL and CRP in meaningful ways.

6.4. LIMITATIONS AND FUTURE WORK

The Equity-Centered Curricular Crosswalk was designed and iterated with respect to a specific curricular purpose (4th grade science+CS) and pilot tested with only a few teachers and classrooms in a single geographic location. Our hope is that this crosswalk will be applicable to other subject areas, grade levels, and geographic locations. There is a need for additional curriculum development to learn the extent to which it applies to other project-based instruction. Additionally, the same project team worked closely and concurrently to develop both the Equity-Centered Curricular Crosswalk and the curriculum module. We have not yet learned the extent to which others can apply the crosswalk to their own planning of equity-focused project-based instruction. For example, our team spent a great deal of time reflecting on the distinct attributes of CRP and UDL and how these could be applied to project based science and CS instruction. This deep reflection influenced our approach to using the crosswalk to develop instructional materials. Future field testing will allow us to solicit teacher feedback on the crosswalk and use it from the beginning in future curriculum development.

7. CONCLUSION

The Equity-Centered Curricular Crosswalk informed the development of an equity-centered science+CS curricular module. This process allowed our team of educators, researchers, and curriculum developers to explore and address the challenges of designing and implementing culturally responsive and pedagogically inclusive approaches. Equity-focused instructional theories hold the promise of increasing participation, access, and feelings of belonging for students from historically marginalized communities, but their impact in classrooms is mediated by the availability of high-quality, equity-focused curricular materials as well as teachers’ ability to implement these materials and apply these theories to transform their teaching practice. Rather than leaving teachers to translate these theories into instruction on their own, which is a significant undertaking, we committed to the task of creating the Equity-Centered Curricular Crosswalk, thus supplying an important link between equity-based instructional theories and the realities of teachers’ classroom practices.

8. ACKNOWLEDGEMENTS

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## APPENDIX A: THE EQUITY-CENTERED CURRICULAR CROSSWALK

### PBL 1: KEY KNOWLEDGE, UNDERSTANDING, AND SUCCESS SKILLS

<table>
<thead>
<tr>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use vocabulary in service of understanding rather than teaching content in isolation. (1.UDL.a)</td>
<td>Connect content to students’ experiences, cultures, and interests. (1.CRP.a)</td>
</tr>
<tr>
<td>Introduce new concepts by anchoring them to previously-taught content and everyday examples, highlighting possible misconceptions. (1.UDL.b)</td>
<td>Listen to and value all students’ ideas. (1.CRP.b)</td>
</tr>
<tr>
<td>Introduce content with different access points. (1.UDL.c)</td>
<td>Help students develop personalized interests and learning goals. (1.CRP.c)</td>
</tr>
<tr>
<td>Make learning goals clear to students and families. (1.UDL.d)</td>
<td>Ask students what they know about the topic. (1.CRP.d)</td>
</tr>
<tr>
<td>Utilize accessible materials (e.g. alternative text on images). (1.UDL.e)</td>
<td>Set learning expectations for all students to challenge stereotypes about who should succeed. (1.CRP.e)</td>
</tr>
</tbody>
</table>

**UDL CRP**

Provide students with clear learning goals tied to content standards.
Deliver content in ways that are actionable and measurable.
Explicitly teach and support success skills such as critical thinking and problem solving, collaboration, and self-management.

**APPENDICES**

**APPENDIX A: THE EQUITY-CENTERED CURRICULAR CROSSWALK**

### PBL 2: CHALLENGING PROBLEM OR QUESTION

<table>
<thead>
<tr>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regularly check for understanding. (2.UDL.a)</td>
<td>Help students explore, identify, or develop personal interests related to the real-world problem, question, or content of their choice. (2.CRP.a)</td>
</tr>
<tr>
<td>Represent content in multiple ways (i.e., pictures, text, audio). (2.UDL.b)</td>
<td>Acknowledge issues of power, privilege, and the historical marginalization of certain groups. (2.CRP.b)</td>
</tr>
<tr>
<td>Consider how students’ lived experiences will impact their understanding of certain concepts. (2.UDL.c)</td>
<td>Discuss similarities among students’ ideas and wonderings to highlight intersections of perspectives, identities, or cultures. (2.CRP.c)</td>
</tr>
</tbody>
</table>

### PBL 3: SUSTAINED INQUIRY

<table>
<thead>
<tr>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model the use of specific strategies to solve problems. (3.UDL.a)</td>
<td>Provide multiple resources to help students research a problem and plan for their final project. (3.CRP.a)</td>
</tr>
<tr>
<td>Provide guidance for use of assistive technologies to access content (i.e., screen readers, switches). (3.UDL.b)</td>
<td>Provide tools that support students in their independent research into a topic of interest. (3.CRP.b)</td>
</tr>
</tbody>
</table>

### PBL 4: AUTHENTICITY

<table>
<thead>
<tr>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use everyday examples to activate background knowledge. (4.UDL.a)</td>
<td>Provide opportunities for students to take an active role in solving real-world problems that are meaningful to them. (4.CRP.a)</td>
</tr>
<tr>
<td>Ensure activities are based on ideas that students find important, interesting, or relatable. (4.UDL.b)</td>
<td>Share your story with students. (4.CRP.b)</td>
</tr>
<tr>
<td>Support student collaboration in high-functioning teams.</td>
<td>Discuss professionals who represent marginalized groups. (4.CRP.c)</td>
</tr>
<tr>
<td>Include relevant connections to sociopolitical issues related to the content. (4.CRP.d)</td>
<td>Provide opportunities for students to take a legitimate role in addressing a challenging problem. (4.CRP.e)</td>
</tr>
</tbody>
</table>

### PBL 5: STUDENT VOICE AND CHOICE

<table>
<thead>
<tr>
<th>UDL</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide students with choices for learning activities, wherever possible. (5.UDL.a)</td>
<td>Provide opportunities for students to identify their own personal and cultural connections to the real-world problem or question. (5.CRP.a)</td>
</tr>
<tr>
<td>Allow students to express their understanding in different ways (e.g., drawing a picture, acting out a sequence, talking it out). (5.UDL.b)</td>
<td></td>
</tr>
</tbody>
</table>

(Contd.)
Act as a guide for students, taking into account their age and PBL experience.

Provide students with opportunities to make decisions.

- Explicitly teach skills of collaboration and self-management. (5.UDL.c)
- Provide tools and resources that structure or scaffold self-management or collaboration. (5.UDL.d)

<table>
<thead>
<tr>
<th>PBL 6: REFLECTION</th>
<th>UDL</th>
<th>CRP</th>
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</table>
| Build in purposeful reflection time and guide students in reflection on what and how they are learning and on the project’s design and implementation. | - Acknowledge difficulty and frustration. (6.UDL.a)  
- Show authentic examples of persisting through difficult problems. (6.UDL.b)  
- Model strategies for persistence and help-seeking. (6.UDL.c) | - Provide opportunities for students to critically assess, report findings, and document additional questions and wanderings from a social standpoint. (6.CRP.a)  
- Provide opportunities for students to critically examine their own cultural roles within society and in the context of the problem or question. (6.CRP.b)  
- Have students reflect on their perspectives and potential biases. (6.CRP.c) |

Provide rubrics and multiple methods for self-assessment.

PBL 7: CRITIQUE AND REVISION

- Provide feedback that is positive, specific, timely, accessible, and relevant to students. (7.UDL.a)  
- Encourage students to reflect on feedback and make revisions (model norms that value students’ perspectives on this process). (7.UDL.b)  
- Provide multiple types of feedback. (7.CRP.a)  
- Allow students to compare their work and draw from peers’ work. (7.CRP.b)  
- Encourage students to share feedback with one another, including feedback based on their culture. (7.CRP.c)  
- Highlight and embrace diverse student perspectives to solve problems. (7.CRP.d) |

Provide processes for students to give and receive feedback on their work so they can revise their ideas and products or conduct further inquiry.  

Include structured protocols for students to give and receive feedback.  

Establish classroom norms that value persistence and mistakes, critique and revision.

PBL 8: PUBLIC PRODUCT

- Give students choice during the product design process. (8.UDL.a)  
- Provide opportunities for students to share their work and successes with one another. (8.UDL.b)  
- Help students express their knowledge and understanding through their product. (8.CRP.a)  
- Ensure that students attribute credit to others whose work inspired their own products. (8.CRP.b) |

Provide an opportunity for students to demonstrate their learning by creating a product that is presented, shared, or offered to people beyond the classroom.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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