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Designing Customization Technologies That Support Teachers to Integrate Social Justice into Science Teaching

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Designing Customization Technologies That Support Teachers to Integrate Social Justice into Science Teaching

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Abstract

Designing customization technologies that support teachers to integrate social justice into science teaching

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Over the last decade, the demands on secondary science teachers have shifted to encompass a new range of objectives. Science teachers need support in their efforts to be responsive as they navigate shifting demands in the teaching profession: new state standards, an ever-diversifying student body, and a drive to integrate social justice into science learning. In the US, for example, the K-12 population has immensely diversified, necessitating curriculum adaptations to support the diverse lived experiences and range of prior knowledge represented in their classrooms. Moreover, new curriculum standards such as the Next Generation Science Standards in the US, have required teachers to adapt curriculum materials to meet new performance expectations. Further, technology has become ubiquitous in classrooms, requiring teachers to learn how to meaningfully integrate new tools into their practice. My dissertation project explores how to support teachers as they navigate these emerging trends within the context of a Research Practice Partnership devoted to promoting coherent science learning in technology-enhanced learning environments.

The studies presented in this dissertation are guided by the overarching research questions: *How can we leverage technology to support teachers in their efforts to be more responsive to the needs and ideas of their students?* Taken together, the three studies presented in this dissertation shed light on teachers' trajectories for customizing curriculum to be more responsive, their trajectories for teaching science for social justice, and their trajectories for leveraging technology as a support for their teaching practice.

Specifically, the first study leverages the Knowledge Integration Framework to design and study a professional development workshop to empower teachers to customize their curriculum to better support their students develop understanding of NGSS performance expectations. The workshop activities and supporting technologies foreground pedagogy and emphasize using student work as evidence to inform customization decisions. The second study applies the professional development model from the first study to support teachers to customize the curriculum to feature social justice issues. The study follows the development and implementation of the units with three teachers across two school years. The third study focuses on the design and implementation of automatic scoring models that increase teachers' access to the social justice and science ideas students use to explain the focal phenomena in the units designed in the second study. Across the

studies, the findings have implications for expanding our understanding of Knowledge Integration pedagogy by integrating social justice principles and for the design of technologies that support teachers in principled customization.

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Chapter 1: Introduction

This research is guided by the overarching research question: *how can we leverage technology to support teachers in their efforts to be more responsive to the needs and ideas of their students?* I particularly address how technology can support science teachers in their efforts to be responsive as they navigate shifting demands in the teaching profession: new state standards, an ever diversifying student body, and a drive to integrate social justice into science learning. In the US, for example, the K-12 population has immensely diversified (Digital Promise Global, 2016), necessitating curriculum adaptations to support the diverse lived experiences and range of prior knowledge represented in their classrooms. Moreover, new curriculum standards such as the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) in the US, have required teachers to adapt curriculum materials to meet new performance expectations. Further, technology has become ubiquitous in classrooms requiring teachers to learn how to meaningfully integrate new tools into their practice.

My dissertation explores how to support teachers as they navigate these emerging trends within the context of the WISE (Web-based Inquiry Science Environment) Research Practice Partnership (RPP) which is composed of learning scientists, designers, computer scientists, teachers and students. The RPP supports teachers through workshops where they customize WISE curriculum and reflect on student work; classroom implementations where they use a learning analytics inspired dashboard; and reflections that lead to refinements of their instruction. The goal of these RPP activities is to support teachers in their ability to be more responsive to students through their in-the-moment instructional decisions and their iterative customization of curriculum. I use the Knowledge Integration Instructional Framework (Linn & Eylon, 2011) and Social Justice Science Pedagogy (SJSP; Morales-Doyle, 2017) to guide the design of the curriculum, RPP activities and learning analytics used by the RPP. More details about the RPP can be found in the General Methods section of this chapter.

Research questions

The first study in my dissertation research, Study 1, is a longitudinal design study across three iterations of an annual summer workshop where the RPP engages in activities that support teacher customization of NGSS-aligned curricula. Across three iterations of the workshop, we varied the way we supported teachers to access their students' thinking, how we made visible the pedagogical framework that guided the design of the curricula, and the technology that facilitated the customization. This work is guided by two research questions: *How do improvements in the representation of the pedagogical framework support teachers' consideration of pedagogy while customizing?* and *How do refinements in providing access to student work support teachers to make sense of and customize in response to students' ideas?*

The next study in my dissertation, Study 2, examines how these RPP workshop activities function when supporting teachers as they specifically customize and implement units that feature issues of social and racial justice. I examine the development of three focal teachers as they participate in partnership activities, customize, and implement these units over the course of two school years. Study 2 is guided by two research questions: *How do teachers shift and develop their perspectives on the relationship between social justice and science over the course of the project?* and *How do the RPP activities support teachers to integrate Knowledge Integration Pedagogy and Social Justice Science Pedagogy in their classrooms?*

In my third dissertation study, I explore the development and use of a teacher dashboard that supports teachers to assess how their students are integrating typical disciplinary ideas with their understanding of racial justice within the context of the customized units. Previous work has illustrated the potential of learning analytics designed using the KI Framework to support teachers as they guide their students to develop deep understanding of complex science concepts, integrating ideas across the three NGSS dimensions (Gerard et al., 2020; Wiley et al., 2023). Building on this research, I seek to design tools that support teachers as they guide their students to integrate their understanding of typical disciplinary concepts with understanding of social justice issues. Further Study 3 builds on findings from Study 1 that suggest providing a dashboard for teachers during instruction and again during summer workshops supports them to access their students' ideas and use them to inform customization decisions. This study also builds on pilot findings that suggest teachers need additional support to assess how their students are integrating their understanding of disciplinary phenomena with understanding of social justice issues (Bradford & Gerard, 2022; Bradford et al., 2023). Study 3 is guided by the following research questions: *How can we develop a natural language processing model that captures students' integrated understanding of disciplinary content and related social justice issues?, How does the dashboard support teachers to interpret and respond to their students' ideas?* and *How does teacher intervention following review of the dashboard, combined with the activities in the unit, impact student learning?*

Motivations

My dissertation work is deeply informed by my perspectives as a former high school math and science teacher for students with special needs. My research interests have been shaped and inspired by my experiences as a teacher and as a researcher working with partner teachers in the WISE RPP. Throughout these experiences, I've seen firsthand that teachers deeply want to be able to respond to their students, rise to the occasion of addressing current challenges in our society, and meet new demands of the teaching profession. For example, as schools adopted the NGSS, our partner teachers were overwhelmed with the opportunity of creating their own curriculum and figuring out what materials align to the new standards. In the absence of standards-aligned curriculum, they found themselves pouring through online resources and cobbling them together to create lessons. They needed support to figure out what were quality materials and what materials would meet the needs of their students as they developed mastery of the new standards, supporting their students to develop integrated understanding across the NGSS dimensions.

As another example, in 2020, our partner teachers brought up new concerns in the wake of the inequities laid bare by the COVID-19 pandemic and the racial reckoning that ensued after the murder of George Floyd. Our teachers recognized a need to again shift their teaching and curriculum so they could support their students to understand systemic causes of inequity and guide students to see how they could use science to address injustices. The partner teachers' ideas broadened the focus within our RPP and initiated our work to integrate local social justice issues into our units.

These examples illustrate how the WISE partner teachers' goals for responding to their students have shaped the work of the RPP. This dissertation work aims to understand how to leverage technology and an RPP community to support teachers in achieving such goals.

Theoretical Foundations

Knowledge Integration and Social Justice Science Pedagogy

This dissertation draws on the constructivist perspective on learning (Inhelder & Piaget, 1958). Constructivism holds that learners construct their knowledge through active sensemaking, rather than being passive recipients of knowledge. From this perspective, learning happens as people solve problems and explore phenomena, working to make sense of these experiences through the lens of their prior understandings. Within this perspective, I adopt the stance that the learners' prior knowledge serves as a productive resource for continued learning (e.g., Hammer, Elby, Scherr, & Redish, 2005; Smith III, diSessa, & Roschelle, 1994). This stands in contrast to the view that misconceptions need to be confronted or replaced (e.g., Brown & Clement, 1989; Resnick, 1983). We view learning instead as involving distinguishing when ideas hold explanatory power and when they do not (Minstrell, 2001). We recognize that learning, for both students and teachers, is sociocultural, deeply influenced and mediated by the environment in which it occurs (e.g., Bransford, Brown & Cocking, 2000) and the objects, tools, and technologies used by learners (Gee, 2008; Walkoe, Wilkerson, & Elby, 2017).

Specifically we bring together Knowledge Integration (Linn & Eylon, 2011) and social justice-centered science pedagogy (SJSP; Morales-Doyle, 2017). SJSP articulates a vision of science education that honors students' ideas, values epistemic diversity, maintains high expectations for students' disciplinary learning, and encourages the development of critical consciousness. It is informed by both culturally relevant pedagogy (Ladson-Billings, 1995, 2009) and critical pedagogy (Freire, 1970). SJSP draws explicit attention to fostering students' critical consciousness, motivating them to question the view of education as a set of settled facts that are transmitted to learners. Aligned with sociocultural theories of learning, SJSP frames education as a process of enabling learners to use science knowledge to identify and understand the factors contributing to inequities and to generate strategies for social change. For example, in his articulation of SJSP, Morales-Doyle (2017) describes a justice-centered chemistry curriculum that connects science-standards aligned content to environmental racism in the distribution of chemical pollution. In addition to learning the science content, students identify how to enact positive change for their community (Morales-Doyle, 2017).

KI aligns with justice-centered science pedagogy in advocating for, respecting, and building on the diverse ideas each student brings to the classroom. KI recognizes that learners hold varied ideas that reflect their lived experiences. It advocates that supporting students to develop coherent understanding involves eliciting students' prior ideas, providing opportunities to discover new ideas, using evidence to distinguish among existing ideas and new ideas, and guiding students to make connections among their ideas to form an explanation or argument (Linn & Eylon, 2011).

Taken together, KI and justice-centered science pedagogy call for supporting science teachers to elicit and value the full range of their students' ideas, to provide opportunities to discover evidence in a variety of relevant and meaningful contexts, to help students use science to distinguish societal inequities, and to explain ways to bring about a more just world. Merging knowledge integration and justice-centered science pedagogy, the partnership designs instruction that builds on the heterogeneity of student ideas related to the study of a science topic. The instruction promotes links between students' ideas about scientific mechanisms and their ideas about the social and political factors that contribute to local, environmental health issues. The designed lesson aims to *elicit* students' observations of the causes and impacts of an environmental hazard, guide students to *discover* new evidence and perspectives, prompt students to *distinguish* who in the community is impacted and which factors (policy and environmental) contribute, and support students to *form connections* to explain causes and formulate solutions. These activities

support teachers to introduce issues of environmental racism while making each student feel that their questions, concerns, and experiences are welcome and valued in the science lesson and that they are empowered to use science to benefit their community.

Responsive Teaching

One mechanism that has been put forward as a piece of supporting more equitable science education is responsive teaching (Kang, 2022). Historically, responsive teaching has been concerned with teachers noticing (e.g. van Es and Sherin, 2002) and responding to the disciplinary spark in student ideas (Elby et al., 2014; Hammer, Goldberg, & Fargason, 2012; Robertson, Scherr, & Hammer, 2015). Recent work, however, is expanding notions of what teachers ought to respond to (Kang, 2022; Louie, 2018; van Es et al., 2017) and highlighting how teacher responsiveness to and noticing of student ideas is inextricably linked to culture, identity and hierarchies of power (Louie, 2018). In order for responsive teaching to be in service of equity, Kang (2022) argues that teacher responsiveness should be comprised of three dimensions: "(a) a teacher's attention to students' needs or struggles, in addition to their contributions as members of a larger classroom learning community; (b) a teacher's interpretation of classroom situations with consideration of race, power, and opportunity to learn, and (c) a teacher's taking of pedagogical actions that expand students' opportunity to learn in classrooms." (p. 209). This perspective broadens responsiveness by opening up the space of what teachers should attend to and foregrounding considerations teachers should hold while interpreting the things they notice in the classroom. Further, these dimensions highlight the essential component of teachers taking pedagogical action based on what they have noticed.

Responsive teaching has typically been concerned with the moment-to-moment interactions between a teacher and student, however, Kang (2022) further broadens notions of responsive teaching by suggesting that responsiveness can occur at different grain sizes: in-the-moment responsiveness, lesson-level responsiveness, and unit-level responsiveness. In-the-moment responsiveness looks like a teacher taking up something a student has uttered in the classroom and is most closely aligned with descriptions of responsive teaching as described in the literature. Lesson-level responsiveness refers to, for example, a teacher deciding to alter a part of a lesson or activity in response to difficulty or interest that arose in a prior lesson. This approach is aligned with formative assessment (Black & Williams, 1998) that is focused on the substance of student thinking (Coffey, Hammer, Levin, & Grant, 2011). Unit-level responsiveness refers to when teachers take pedagogical action to modify the design of a unit in response to student prior knowledge, interest or experience. Study 1 of this dissertation focuses on the iterative designs of a workshop to support teachers in unit-level responsiveness. Study 2 considers teachers responsiveness at all three grain sizes as they occur while teachers integrate social justice into their science teaching. Study 3 examines the role a teacher dashboard plays in supporting both lesson-level and unit-level responsiveness.

Teacher curriculum customization: Supports teacher learning and improves curriculum

When teaching with researcher-designed or commercially available curricula, teachers tend to adapt or customize the materials to better align with their own teaching practices and pedagogical orientations (Matuk, et al., 2016; Remillard, 2000; Schneider, et al. 2005). Teachers often customize materials to make them more relevant for their specific student population (Squire, 2003) or to make them work for students with different cultural and linguistic backgrounds. The term *customization*, particularly in the context of technology-enhanced learning, might signal

personalizing curriculum to individual students. In the context of this dissertation, however, I use the term *customization* to refer to any teacher adaptation of the curriculum to tailor it to their own needs or the needs, interests, and ideas represented in their classroom, broadly speaking.

Throughout this dissertation, I take the stance of Ball and Cohen (1996) who argue that teacher customization of curriculum materials should be reconceptualized as advantageous and an opportunity for teacher learning, rather than something that needs to be minimized to support fidelity of implementation. Engaging teachers in partnership and co-design of curricula through professional development (PD) has been shown to be effective for both teacher learning and student learning outcomes. Engaging teachers in customization activities enables a flexibly adaptive approach to PD (Trautmann & MaKinster, 2010) that supports teachers to adapt existing materials to meet the needs of their students and suit their classroom context without overburdening teachers with the additional job of curriculum designers.

Because teachers possess localized knowledge of their students and understand the constraints of their context, PD that supports them in customization can lead to productive curricular innovations (Randi & Corno, 1997; Squire et al., 2003). Further, PD that supports teacher customization has been viewed as an appropriate balance between the extremes of engaging teachers in full curriculum design and treating teachers solely as enactors of the curriculum (Squire, 2003). As stated by Barab and Luehmann, "the process of dissemination [of curriculum] is not simply "rubber-stamping" the same program into multiple contexts; rather, the process of large-scale adoption involves additional, individual teacher-directed design, fitting, and adaptation for local circumstances" (p. 454, 2003). Using PD to support customization is an effective approach for scaling and disseminating innovative, reform-based curriculum. Additionally, it has been found that engaging teachers in customization and co-design activities during PD supports teachers to better integrate education technologies into their teaching (Kafyulilo, et al., 2015) indicating another advantage of focusing on customization during PD.

In this dissertation, I am particularly interested in how teachers' customization reflects pedagogical action for in-the-moment, lesson-level and unit-level responsiveness. I am interested in both the in-the-moment and lesson-level customization that occurs as teachers make instructional decisions within the discretionary spaces (Ball, 2018) of their classroom (e.g. raising up a student idea, finding a new resource to share, shifting the structure of an activity) and the customization that occurs when teachers reflect on past teaching of a unit and plan to teach it again. While unit-level customization can include teachers organizing for curricular changes at the school or district level, I focus on teachers working individually or with a small set of partner teachers to customize units for use in their own classrooms. I also adopt the stance that teachers should consider engaging their students' disciplinary sparks, leveraging their students' cultural resources, and fostering student identity when making customization choices and that teachers (and researchers) should work to develop awareness of how we decide what to respond to and why.

Approaches to support teachers in responsive curriculum customization

To engage in effective customization, teachers need opportunities to connect their ideas about student understanding to their pedagogical decisions and the design of curriculum (Darling-Hammond & Snyder, 2000; Davis, et al., 2011). One approach to doing so is through professional development (PD) experiences that develop teacher's pedagogical design capacity (Brown, 2009; Brown and Edelson, 2003; Remillard, 2005). Developing pedagogical design capacity is particularly important for supporting teachers' customization because, as Davis and Krajcik report, "promoting a teacher's pedagogical design capacity can help him participate in the discourse and

practice of teaching; rather than merely implementing a given set of curriculum materials, the teacher becomes an agent in its design and enactment." (p. 3, 2005). As teachers' pedagogical design capacity increases, so does their capacity to effectively adapt and customize curriculum to meet their students' needs (Beyer & Davis, 2012).

Developing teachers' pedagogical design capacity during PD requires making visible the ways various curricular materials can be used to accomplish teaching goals. In some instances, this can be done through the curriculum itself, serving as a way to support teachers to integrate new ideas with their existing knowledge and teaching practice (Ball and Cohen, 1996). Another approach is to leverage educative materials (e.g., Arias, et. al., 2016; Beyer & Davis, 2009; Schneider & Krajcik, 2002) where the curriculum is designed with supports that enable both teacher and student learning from the materials. Designing educative materials has been found to support teachers to make connections between learning theory and practice (Davis and Krajcik, 2005). For example, Beyer and Davis (2009) designed educative supports that accompanied lesson plans that prompted student teachers to consider important teaching principles, like making thinking visible, while making decisions about how to adapt lesson plans and curriculum materials. They also included rationales for why each principle was important to consider in that lesson. They found that student teachers were able to productively consider pedagogical principles while adapting materials when they were using the educative supports, but didn't continue to do so without the materials (Beyer & Davis, 2009).

Studies on fostering pedagogical design capacity and the use of educative materials suggest that curriculum paired with educative support could support teachers to make pedagogically-informed curriculum customizations. However, teachers' ability to learn from educative materials depends on both the teachers' familiarity with the underlying pedagogy of the curriculum and the complexity of the materials (Remillard, 2018). Attending to the interpretability of the educative materials and designing PD opportunities that facilitate teacher engagement with them are critical for ensuring they actually support teacher customization.

Professional development supporting teachers to engage in responsive curriculum customization should also feature opportunities for teachers to consider evidence of student learning to inform their customizations. Prior research has demonstrated the importance of reviewing student work for supporting teachers to refine and improve their instructional approach and to adapt curriculum materials so that they respond to student needs (Williams, et al., 2004). Reviewing student work to inform teaching decisions promotes responsive teaching and can lead to better learning outcomes for students (Ruiz-Primo & Furtak, 2007). Incorporating review of student work into PD supports teachers to reflect on their instruction and to develop strategies to enhance student learning (Gerard, et al. 2011; Gerard, Spitulnik, & Linn, 2010). Further, PD that offers the opportunity to discuss students' ideas with colleagues can support changes in teaching practice following the PD (Burton et al., 2013).

The first study in this dissertation (Chapter 2) explores the design of a PD workshop that both follows and makes visible KI pedagogy in service of supporting teachers to customize NGSS-aligned science curriculum in ways that are responsive to their students, informed by evidence of student learning, and pedagogically coherent. In the study, we iteratively refine the approach to making the KI pedagogy underlying the curriculum visible to teachers and the approach to increasing teacher access to their students' ideas. The second study (Chapter 3) explores how to refine this model to support teachers with the additional aim of customizing curriculum to integrate local social justice issues. The study follows three teachers as they participate in the PD workshops and teach the customized units over two school years. The third study examines the development

of a learning analytics report to provide teachers with increased access to students' thinking about the intersection of science and social justice issues to support them to make responsive instructional decisions while teaching and leverage evidence while customizing during summer workshops.

General Methods, Participants, and Technologies

Methodological Approach

The studies in this dissertation are Design-based Research (e.g. Sandoval & Bell, 2004; DBR), conducted using mixed methods (e.g. interview, thematic coding, statistical analysis of pretest and posttest scores). The studies all take place in context rich environments like classrooms and professional development workshops. The aim of DBR is to combine rigorous theory with engineering principles to understand and address problems of practice (Sandoval & Bell, 2004). To that end, the studies that make up this dissertation are centered on problems teachers face in the classroom: a need to meet new standards, the desire to leverage student thinking in instructional decision making, and integrating issues of social justice into standards-aligned science curriculum.

WISE Research Practice Partnership

This dissertation research has been conducted within the context of the WISE (web-based inquiry science environment) research practice partnership (RPP). The WISE RPP consists of students, teachers, learning scientists, designers, and computer scientists. All teachers in this partnership are middle and high school science teachers in a large metropolitan area of a Western state. Many of these teachers have been members of the partnership for over five years and routinely participate in professional development workshops and research studies.

Study Participants

The first study in this dissertation is focused on the design and impact of our professional development workshops on teachers' approach to customizing the WISE curriculum. The participating teachers include all those from the RPP who attended at least two of the summer workshops between Summer 2018 and Summer 2020. Studies two and three focus on three teachers from the partnership: Mary, Rosie, and David. All three of these teachers have been members of the RPP for at least 3 years and have been teaching for at least 8 years. These teachers were selected because of their commitment to teaching inquiry science with technology and their eagerness to integrate social justice into the technology-enhanced curriculum and teaching.

Studies two and three also include Mary, Rosie, and David's students as participants. The students engaged with the WISE unit selected by their teacher either independently or in teacher-assigned groups. Students who completed the majority of the unit and the pretest and posttest were included in the analyses.

Technologies

All three studies in this dissertation are supported by the WISE (Web-based Inquiry Science Environment; wise.berkeley.edu) platform. WISE is an open source authoring and customization environment (ACE) that includes features to support students, teachers, and researchers. WISE features online, inquiry science units that are aligned with the middle school

next generation science standards (NGSS). The units are freely available and can be accessed and customized by educators around the world. The units are continuously updated in response to feedback from students and teachers, and in response to findings from research studies across the WISE RPP.

The WISE platform offers student-facing curricula that engage students in KI cycles (Linn & Eylon, 2011) to support the development of integrated understanding. Students have the opportunity to interact with simulations, models, their peers' ideas, and a variety of datasets to explore science phenomena. The WISE platform logs students' work as they engage with the units including their written responses to open response questions, multiple choice responses, and graphs and tables. The platform also logs students' revisions which enables teachers and researchers to see how students update their thinking in response to engaging with additional ideas or activities.

The WISE platform also provides teachers with access to a suite of teacher tools. These tools give teachers the ability to group and ungroup students, review logged student work, and grade and leave feedback for students. Additionally, a number (3-5) of the open responses questions throughout each unit are automatically scored (this will be discussed in depth in Study 3). Teachers are able to view both student responses and the scores the responses have been assigned. Further 1 or 2 of these automatically scored items are considered milestone items where students are tasked with integrating ideas across the NGSS domain (disciplinary core ideas, cross cutting concepts, and science and engineering practices). For milestone items, teachers can access a dashboard called the Teacher Action Planner (TAP) where they can see histograms of their classes' scores on multiple NGSS dimensions as well as toggle between individual scored student responses and recommended teaching actions (e.g. have students pair up to exchange ideas and then review one of the interactive models) that are adaptive to the score profile in their classroom.

Organization

This dissertation is organized into three studies to answer the overarching research question: *How can we leverage technology to support teachers in their efforts to be more responsive to the needs and ideas of their students?* All three studies will provide insight into how we best leverage technology to support teachers to be responsive to their students as they navigate emerging issues in science education such as social justice. The research will illustrate how these emerging ideas can be integrated with existing standards and powerful pedagogy. The studies will provide insight into the design of RPP professional development activities that support teachers to respond to their students' ideas while they adapt their curriculum and instructional approach to integrate social justice into their teaching.

Taken together, the three studies presented in this dissertation shed light on teachers' trajectories for customizing curriculum to be more responsive, their trajectories for teaching science for social justice, and their trajectories for leveraging technology as a support for their teaching practice. The findings have implications for expanding our understanding of Knowledge Integration pedagogy by integrating social justice principles and for the design of technologies that support teachers in principled customization.

The chapters that follow are organized as such:

- Chapter Two: Iterative Design of Workshop to Support Teacher Customization of Curricula (Study 1)
- Chapter 3: Teacher Trajectories in Teaching Science for Social Justice (Study 2)

- Chapter 4: Developing an AES Model for Student Explanations of Social Justice Science Issues (Study 3)
- Chapter 5: Discussion and Conclusions

Chapter 2: Iterative Design of a Workshop to Support Teacher Customization of Curricula

Chapter overview

In this chapter, I report on design-based research to refine a professional development workshop that supports teachers to customize online curricula. As the work reflects the collaboration across multiple members of the research practice partnership, I will use first person plural pronouns throughout. Over the course of three years, we iteratively designed representations to make the knowledge integration pedagogy of the curricula visible. We studied ways to make the work of students using the curricula actionable for participating teachers. Using teachers' written reflections across multiple iterations of the workshop and research fieldnotes as data, we developed inductive codes to describe participants' trajectories across the three iterations of the workshop. Initially, when participants realized they could customize the online curriculum, they developed feelings of ownership. Then, as participants deepened their understanding of the pedagogy, they began to use it to evaluate their own instruction. The trajectory culminated in participants connecting the pedagogy to student work from their own classroom. This led to a shift from focusing on remedies for misconceptions to seeking opportunities for building on students' nascent ideas when customizing. The workshop refinements empowered teachers to mobilize the pedagogy to interpret their students' work to inform their customization decisions.

Major issues and objective

When teachers implement new curriculum materials, they often customize instruction to align with existing classroom practice or to meet other goals. This is particularly likely to happen when the materials are designed based on a pedagogical framework that differs from the teacher's typical approach (Matuk, et al., 2016; Remillard, 2000; Schneider, et al. 2005). We believe the process of teacher customization can lead to curricular innovation when supported through sustained professional development, in contrast to prior work that has been more focused on fidelity of implementation (e.g. O'Donnell, 2008; Penuel & Means, 2004; Songer & Gotwals, 2005). Supporting teachers to customize effectively involves providing teachers with relevant evidence to inform their decisions. Although attending to student work and ideas has been shown to lead to more impactful instruction (e.g. Carpenter, et al., 1989; Coffey, et al., 2011; Fennema, et al., 1996), teachers often lack time to gather and respond to data they perceive as relevant when customizing (Ingram, et al., 2004; Kerr, et al., 2006). As such, teacher customization of curriculum can lead to mixed outcomes for students (e.g. Bismack et al, 2015; Davis, et al., 2017; McNeil, 2009). When teachers anchor their customizations in evidence, particularly from student work, however, they are able to make better customizations (Gerard, et al. 2010). Additionally, providing teachers with educative materials that support them to connect the evidence they gather from student work to the pedagogical design rationale behind curriculum materials can support them to consider the goals that can be accomplished with various materials (Davis & Krajcik, 2005) and make pedagogically grounded customization decisions.

In this study, we report on three design iterations and explore the impact of a professional development workshop that takes advantage of technology to make curriculum designers' pedagogical design intentions visible alongside the curriculum and to enable teachers to use student work to plan customizations. Specifically, the workshop design engages teachers in goal setting, analyzing student work to identify possible revisions, and designing customizations to the curriculum content and embedded assessments based on their analysis. This study reports on three

design iterations of the workshop activities, materials, and technologies. Each iteration of the workshop was offered in the summer. Following the workshop teachers implemented their customized units, and many returned for a subsequent, refined workshop the next year. Workshop refinements were made between each summer iteration and were based on the researcher and teacher reflections at the end of each workshop day. The workshops supported teachers to customize instruction while attending to contextual constraints such as available classroom time and new standards. Furthermore, we designed technologies to help teachers with limited time to efficiently gather data about student learning, such as logged student work and automatically generated scores, to help inform their customizations. The design took advantage of the ability of the online system used by participating teachers to log student work and display this work for teachers to analyze before they plan and implement their customizations.

The workshop design also made the pedagogy behind the curriculum units teachers were customizing visible in several ways. We helped teachers build connections between their own practices and the pedagogical framework used to design the units. We also created a Curriculum Visualizer that displays the pedagogical intention of each activity in the unit. This was done in order to support teachers to (a) consider pedagogical implications as they planned revisions and (b) support teachers to distinguish changes that increase the impact of their curriculum.

We investigate how these supports enable teachers to appreciate the instructional goals of the materials and make connections to their students' ideas. We describe the three design iterations and the impact design changes had on teachers' use of student work and pedagogy while customizing. Our research questions are:

- How do improvements in the representation of the pedagogical framework underlying the curriculum facilitate teachers' consideration of pedagogy while customizing?
- How do refinements in providing access to student work support teachers to analyze that work as they customize the curriculum and their instructional approach?

Theoretical Underpinnings

Professional development for teacher customization

When teaching with researcher-designed or commercially available curricula, teachers tend to adapt or customize the materials to better align with their own teaching practices and pedagogical orientations (Matuk, et al., 2016; Remillard, 2000; Schneider, et al. 2005). Teachers often customize materials to make them more relevant for their specific student population (Squire, 2003) or to make them work for students with different cultural and linguistic backgrounds. In the US, for example, the K-12 population has immensely diversified (Digital Promise Global, 2016), necessitating curriculum adaptations to support the diverse lived experiences and range of prior knowledge represented in their classrooms. Moreover, new curriculum standards such as the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) in the US, require teachers to adapt curriculum materials to meet new performance expectations.

Given teachers' tendency to customize curriculum, it is effective to engage teachers in curriculum customization during professional development (PD). While some conceptualize PD as a tool to support fidelity of implementation (e.g. O'Donnell, 2008; Penuel & Means, 2004; Songer & Gotwals, 2005), we take the stance of Ball and Cohen (1996) who argue that teacher customization of curriculum materials should be reconceptualized as advantageous and an opportunity for teacher learning. Engaging teachers in partnership and co-design through PD has been shown effective for both teacher learning and student learning outcomes. Engaging teachers

in customization activities enables a flexibly adaptive approach to PD (Trautman-MaKinster, 2010) that supports teachers to adapt existing materials to meet the needs of their students and suit their classroom context. Because teachers possess localized knowledge of their students and understand the constraints of their context, PD that supports them in customization can lead to productive curricular innovations (Randi & Corno, 1997; Squire et al., 2003). Further, PD that supports teacher customization has been viewed as an appropriate balance between the extremes of engaging teachers in full curriculum design and treating teachers solely as enactors of the curriculum (Squire, 2003). As stated by Barab and Luehmann, "the process of dissemination [of curriculum] is not simply "rubber-stamping" the same program into multiple contexts; rather, the process of large-scale adoption involves additional, individual teacher-directed design, fitting, and adaptation for local circumstances" (p. 454, 2003). Using PD to support customization is an effective approach for scaling and disseminating innovative, reform-based curriculum. Additionally, it has been found that engaging teachers in customization and co-design activities during PD supports teachers to better integrate education technologies into their teaching (Kafyulilo, et al., 2015) indicating another advantage of focusing on customization during PD.

In this paper, we report on the design of a PD workshop that joins with the recent calls to move away from a focus fidelity of implementation (e.g. Buxton, et. al., 2015) and better understand how to support teachers in developing their capacity to customize curriculum. In the next sections, we review prior work on teacher learning that informed our workshop design principles: using learning theory to inform workshop activities, increasing teacher access to evidence from student work and making pedagogy visible.

General Principles: PD for use of technology-enhanced curriculum

If we are to use professional development to support teachers in productive curriculum customization, it is important to consider the design of these PD opportunities. For teachers teaching with and customizing technology-enhanced curriculum, particular consideration needs to be given to how the opportunities integrate the educational technology. In this context, teachers need professional learning that supports them to incorporate new technologies into their teaching practice. Reviews of professional development to support the integration of technology into teaching have found that engaging teachers in PD opportunities that are designed to follow a particular theory of learning and feature constructivist-oriented learning activities are most effective (Lawless & Pellegrino, 2007; Gerard et al., 2011). In general, it has also been found that PD should engage teachers in active learning experiences and be situated in meaningful contexts (Darling-Hammond et al., 2017; Voogt, 2011) such as their own classroom practice. This is particularly important in technology-enhanced contexts, because teachers need support to consider how they will integrate the learning technology with both curriculum and their pedagogy. Effective PD accompanying technology-enhanced curriculum should integrate the technology to provide opportunities for learning how to teach with the technology as opposed to just learning how to use the technology (Lawless & Pellegrino, 2007). Further, the integration of technology during PD elicits teachers' prior ideas and strengths, enabling PD facilitators to help teachers build on those strengths and understand the role the teachers envision the technology playing in their classrooms (Wilkerson et al., 2016). By using the technology during PD in ways that reflect constructivist learning theory can support teachers to consider how to use the technology in ways that align with the learning theory that guides their teaching.

Use of student work for teacher learning

In addition to providing theory-aligned, active learning opportunities for teachers, professional development for customization should also feature opportunities for teachers to consider evidence to inform their customizations. Teachers are currently encouraged to make data-driven and evidence-based decisions about their teaching practice. In studies of teacher use of data, teachers often find classroom assessments and reviewing their students' work to be the most meaningful and effective (e.g. Kerr, et al., 2006). However, teachers need time and support to make use of data they perceive as relevant which is often in tension with other teaching responsibilities (Ingram, et al., 2004; Kerr, et al., 2006). Additionally, study of novice teachers indicates that they rely on observations and listening to students speak to make instructional decisions while teaching, but often don't employ examination of student written work or products because of the time and preparation that doing so requires (Kohler, et al., 2008). Making use of student work to inform teaching decisions is a skill that teachers need to develop and often requires time that teachers do not have. While challenging, when teachers do engage in review of their student work to inform their teaching decisions, they are more likely to engage in responsive inquiry teaching since it requires teachers to consider students' ideas and current understanding rather than adhering to a teacher-driven plan. Doing this can lead to greater inquiry learning outcomes for students (Ruiz-Primo & Furtak, 2007). Review of student work is also an important approach for supporting teachers to refine and improve their instructional approach and to adapt curriculum materials so that they respond to student needs (Williams, et al., 2004).

Because teachers need opportunities to evaluate what they consider to be valid evidence of student learning and to reflect on their beliefs about student thinking (Tomanek, Talanquer, & Novodvorsky, 2008), incorporating analysis of student work during PD conducted while teachers have more time at their disposal can be effective. There are many other benefits of incorporating analysis of student work into PD. In a review of PD for teaching technology-enhanced curriculum, Gerard et al. (2011) report that incorporating review of student work into professional development has been found to support teachers to reflect on their instruction and to develop strategies to enhance student learning. In the specific context of PD focused on customizing curriculum, analysis of student classroom assessment data led to customizations supporting inquiry instruction and leading to improved student learning outcomes (Gerard, Spitulnik, & Linn, 2010). One other advantage for including review of student work in PD is that teachers have the opportunity to discuss their students' ideas with colleagues. Burton et al. (2013) found that teachers demonstrated changes in their teaching practices only after having the opportunity to present their student work to peers. They argue that reviewing and presenting student work products was particularly effective because it engaged teachers in viewing the lesson through the lens of a student.

Pedagogical design capacity: Making pedagogy visible

Considering evidence of what students need is only one part of supporting teachers to make effective customization decisions. During professional development, teachers also need opportunities to connect their ideas about student understanding to their pedagogical decisions and the design of curriculum (Darling-Hammond & Snyder, 2000; Davis, et al., 2011). PD that supports teachers to make these connections can be said to develop teacher's pedagogical design capacity (Brown, 2009; Brown and Edelson, 2003; Remillard, 2005). Developing pedagogical design capacity is particularly important for supporting teachers' customization because, as Davis and Krajcik report, "promoting a teacher's pedagogical design capacity can help him participate in the discourse and practice of teaching; rather than merely implementing a given set of

curriculum materials, the teacher becomes an agent in its design and enactment." (p. 3, 2005). As teachers' pedagogical design capacity increases, so does their capacity to effectively adapt and customize curriculum to meet their students' needs (Beyer & Davis, 2012).

Developing teachers' pedagogical design capacity during PD requires making visible the ways various curricular materials can be used to accomplish teaching goals. In some instances, this can be done through the curriculum itself, serving as a way to support teachers to integrate new ideas with their existing knowledge and teaching practice (Ball and Cohen, 1996). Alternately, as in the case with educative materials (e.g., Arias, et. al., 2016; Beyer & Davis, 2009; Schneider & Krajcik, 2002), the curriculum can be designed with educative supports that enable both teacher and student learning from the materials. Educative supports designed in such a way can further support teacher connections between learning theory and practice (Davis and Krajcik, 2005). For example, Beyer and Davis (2009) designed educative supports that accompanied lesson plans that prompted student teachers to consider important teaching principles, like making thinking visible, while making decisions about how to adapt lesson plans and curriculum materials. They also included rationales for why each principle was important to consider in that lesson. They found that student teachers were able to productively consider pedagogical principles while adapting materials when they were using the educative supports, but didn't continue to do so without the materials (Beyer & Davis, 2009).

Studies like this suggest the possibility of curriculum paired with educative supports promoting the development of pedagogical design capacity. However, teachers' ability to learn from these materials depends on both the teachers' familiarity with the underlying pedagogy of the curriculum and the complexity of the educative support materials (Remillard, 2018). Their findings indicate the need for PD to support teachers as they engage with such materials as well as the need for attention to the design of the educative supports themselves.

Methods

To answer our research questions, we analyzed teacher reflections across the three workshops held over three years. We connect themes from their reflections to the design iterations. We examine how teachers take advantage of their students' work and connect it to the KI pedagogy to strengthen evidence-based instruction. We had to omit analysis of a third aspect of the workshops, authoring technologies, due to space limitations. A subsequent paper will describe our refinements of the authoring technologies for teachers and the teacher reflections on it.

Participants

Seventeen teachers attended the first workshop, 19 teachers attended the second workshop, and 23 attended the third workshop. Only teachers who attended at least two of the workshops were included for analysis: twenty-five teachers representing 10 schools participated in at least two of the customization workshops. 56% of teachers (14) were present during all three workshops.

Workshop design principle and iterations

Learning Theory-Informed PD: Knowledge Integration Framework

The Knowledge Integration (KI) Pedagogical Framework (Linn & Eylon, 2011) informs both the design of the interactive online science units and the workshop for teachers. The KI framework builds on constructivist perspectives (Inhelder & Piaget, 1958) that acknowledge that

learners bring multiple prior ideas about scientific phenomena into the classroom and engages students in exploring their own and new ideas as they develop coherent understanding. In the context of the online science units, each lesson in the unit follows the research-based KI processes (Linn & Eylon, 2011). Units might start with activities where students make predictions about phenomena to *elicit* their prior knowledge. Next students might *discover* new ideas by engaging with interactive scientific models and discussing ideas with peers. Having accumulated a repertoire of ideas, students then *distinguish* among their ideas by testing their hypotheses in new scenarios or sorting which ideas are relevant under certain circumstances. Finally, students *reflect* on how their new ideas fit with their initial ideas.

We designed the professional development workshops following the same pedagogy as the interactive online science units and implemented the workshops with an online unit using the same technology as the online science units. By using the same technologies and pedagogy, the workshop modeled the instructional approach that it advocated for. Applying the KI framework to the workshop design, we first *elicit* teachers' ideas about their goals for student learning and what they hope to achieve using the unit. Next, we support the teachers to *discover* new ideas about how the unit is functioning in their classrooms through analysis of student work from the unit they are customizing. Teachers analyze student written explanations from key assessments embedded within the unit in conjunction with their recollections of student learning while teaching to determine areas of the unit that need to be strengthened in order for students to achieve mastery of aligned standards. This spurs the teachers to think of ways to customize the unit to strengthen student learning. Next, we introduce the idea of KI pedagogy as a means to *distinguish* which customizations to make and to consider where new activities fit with existing activities. By considering the pedagogical intention of the activities already in the unit, teachers can distinguish how best to integrate new activities. Finally, teachers teach the customized version of the unit and *reflect* on the efficacy of their customizations.

Making the Knowledge Integration pedagogy visible

At the workshop, we made the KI pedagogy underlying the curriculum design visible in several ways. First, we supported teachers to connect KI processes such as distinguishing ideas to examples of activities in their existing practice. This deepened understanding of the pedagogy and of the characteristics of their own practice. Second, we used a visual representation of the KI processes underlying each activity in each unit to illustrate the interactions across processes (Figure 2.1) as an educative support. Lastly, we designed the workshop following the same pedagogical framework, KI, in order to model the instructional approach for teachers.

Connecting KI to teacher practice

In the first workshop we introduced the KI processes and some examples of activities from the units that engaged each process. Then, teachers brainstormed examples of their own activities and classroom practices, recorded them on post-it notes and sorted the examples by KI process. For example, teachers sorted their use of Know-Want to Know-Learned (KWL) charts as eliciting students' ideas and their use of Venn diagram graphic organizers as helping students distinguish among their ideas. In the second workshop, researchers similarly demonstrated examples from the units, and illustrated how each lesson of the unit engages students in each of the KI processes. Then teachers, many of whom were already familiar with the KI processes from the first workshop (see Methods for details), met in small groups to discuss how their initial customization ideas aligned with the KI processes. In the third workshop, we supported the teachers to connect the KI

pedagogy to their classroom assessment. We generated a sample of their students' responses from the log files and annotated the responses by their students' degree of integrated understanding.

Visual representation of KI in the unit

In the first workshop we used notecards to represent the lessons in each unit and color-coded post-it notes to represent the individual KI processes in each activity in the unit. We decided to use post-it notes because they enabled teachers to see the pedagogical structure of the unit while also supporting teachers to modify or rearrange existing activities, and add in new activities of their own. Teachers found the notecards and post-its useful for understanding the design of the units and inserting their own activities. However, they were difficult to use during collaboration and hard to share. In the second workshop, we transitioned to using online technology to represent the units in order to increase opportunities for collaboration and to make it easier to keep track of curriculum customizations.

(a) (b) (c)

Figure 2.1. Progression of the planning tool: (a) Year 1, (b) Year 2 and (c) Year 3. The color of each post-it/text box/slide represents the KI process engaged by the activity written on it: Pink for eliciting ideas, orange for discovering ideas, green for distinguishing ideas, and blue for reflecting on ideas.

We created an online version of the notecard and post-it approach using Google slides. We initially created one slide for each lesson, with colored boxes representing the processes in the activities. Teachers found this approach frustrating because they could not easily add their own activities and the activities were organized only by KI process and not instructional order. The third representation improved the use of Google slides. Each activity in the lesson was assigned a separate slide, making it easy to rearrange the sequence and to add new activities. As shown in the figure, a black slide was used to indicate a new lesson. Each step in the lesson was then represented with a slide color-coded for the KI process it represented. This enabled participants to appreciate the overall structure of the unit as well as the role of each activity. Teachers could easily add new activities from color-coded template slides, prompting them to consider the KI process engaged by the activity they intended to add. Doing so prompted teachers to consider the relationship between their own pedagogical approach and the approach intended by the curriculum. This representation also enabled greater collaboration among teachers customizing the same unit. They could easily share the copy of the unit they were working on and engage in dialogue with other teachers or researcher by using the comments feature in Google. This representation further had the advantage of enabling teachers to move between focusing on the details of one activity and focusing on the composition of the unit as a whole.

Making student work accessible

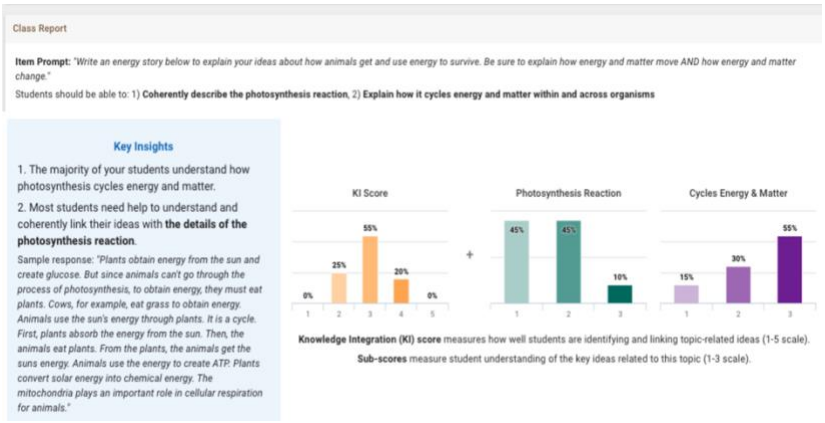
We engaged teachers in analysis of student work to help inform the customization decisions they make and refined our design for accessing student work across the three workshops (Figure 2.2). In the first workshop, teachers were grouped by unit. Each group received a spreadsheet with a random selection of student responses to an open explanation question in the unit. For each unit, we selected an open explanation question that assessed one of the standards addressed by the unit and came at a point after students had engaged in a full KI cycle around that standard. Teachers found the examples informative for discussing the unit and student understanding with their peers. They were reluctant to use these examples when customizing their own instruction, preferring to rely on their classroom observations (e.g. Kerr, et al., 2006). This motivated a redesign before the next year of the workshop to connect teachers to their own students' work. In the second workshop, we developed learning analytics that summarized student work on an open explanation question in the unit and created personalized summaries for each teacher, based on the responses of their students. Teachers found the summary useful for explaining their students' progress and highlighting specific ideas that students needed more support to develop. They continued to also rely on their own recollections. In the third workshop, we enabled teachers to examine their student work immediately during instruction as well as during the workshop. During instruction, we used the learning analytics to generate the summary of student work as the teacher implemented the unit. Some teachers began identifying ways to build on their students' ideas when they got the summary during instruction and further developed their ideas during the workshop. When teachers reviewed the analytics again during the workshop, they were re-grounded in their experience of teaching the unit. At the workshop, we also engaged teachers in sorting a sample of their own students' responses by the level of KI to deepen their understanding. After they scored the responses, we had teachers compare their sorting with researchers' annotated comments on their students' responses. This activity was intended to promote a deeper understanding of what the scores mean in terms of their students' ideas.

The technology-enhanced units logged student work as they progressed through instructional activities. Across the three workshops, we increased access to the logged student work generated in each teachers' own classroom to use as evidence for customization goals. We also helped teachers contextualize their student work by having them analyze it at the same time as they were teaching the unit, which made stronger connections between the work reviewed at the workshop and their experience of teaching the unit.

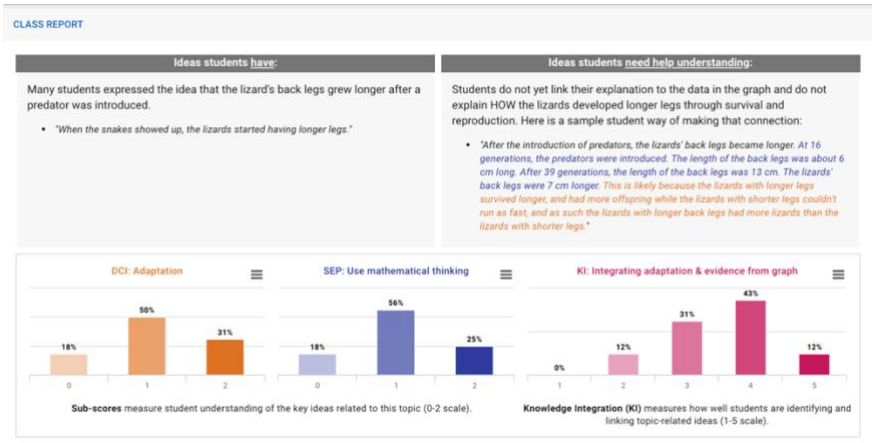
Students Responses

#	Response	Team comments
1	Human activities global temperature to increase because things things like cars and factories let out carbon dioxide which is a type of greenhouse gas, and greenhouse gases don't let heat escape so the temperature will escape. Carbon Dioxide is a very common gas that is in the air so temperature will increase. She can, not use her car as much, she can do a petition, walk, ride a bike, or carpool, she could also campaign to stop many factories.	
2	Air pollution is causing global warming. Air pollution is caused by burning non renewable resources such as oil and coal. Gwen can help by saving energy in any possible way.	
3	Human activities such as going in cars and also building factories produce greenhouse gases. These gases will trap heat and also they will heat up the Earth. This will be bad because the Earth will be to hot because of the greenhouse gases. So some examples of what we can do to stop global warming are making sure your car is checked to see that it is not giving out too much gases. Another thing is that you can try to walk or bike rather than go in car.	
4	Humans produce carbon dioxide by breathing out and plant absorb this gas like we do	

(a)



(b)



(c)

Figure 2.2. Representation of students work to guide teacher customization in (a) year 1, (b) year 2 and (c) year 3.

Data sources and analytic procedure

Our data come from teacher written reflections and researcher field notes from each of the three workshops, taking place in June of three consecutive years. At the end of each workshop teachers were asked to write reflections on their experience of the customization process. The online unit guiding the workshop logged teachers' responses to the reflection questions. Teacher responses to the following questions were used in our analyses:

- What are some things you learned or have taken away from engaging in this customization process and sharing with other teachers?
- Was this customization process and reflecting on the KI cycle helpful for you in thinking about how to achieve your NGSS and other curricular goals?
- Do you think you could use this process again to customize another unit you'd like to run?
- Please share any other reflections of feedback you have from the workshop

Teacher responses to all four questions in each year were combined to represent each teacher's reflection for that year. We began coding with three a priori categories reflecting our research questions and design focus on making pedagogy visible and using student work: *Value of KI Pedagogy*, which were statements about the affordances of considering KI during customization; *Use of Student Work*, which were statements about the utility of student work for customization; and *Value of Technology,* which were statements about engaging with the technology to author their customizations in the online units (omitted for this paper). We used inductive coding (Thomas, 2006) to determine themes within each of these categories to uncover trends in how teachers' reflections within the categories evolved over time. The themes represent the most common ideas teachers expressed in each category of reflection. The themes for each category can be found in Table 2.1. While analyzing the reflections, we noticed teachers expressing a sense of ownership of the curriculum, so we added *Sense of Ownership* as a category in our coding scheme. Changes in the way themes were represented and discussed at each workshop illustrate the ways in which the refinement of the workshop activities have shaped the teachers' experiences of and approach to customization.

Table 2.1. Coding scheme and emergent themes for teacher reflections on the workshops

Sense of Ownership	Value of KI Pedagogy	Use of Student Work	Value of Technology
Customization is possible	KI clarifies unit learning objective	Identify misconceptions	Newly aware of tool
Able to meet own goals	KI provides insight into unit design	Identify areas where students struggle	Need individual support to use tools
Able to meet student needs	KI informs customization decisions	Find student ideas to build on	Time consuming to use the tools
Opportunity to integrate resources	KI supports reflection on own practice	Customize to address student needs	Tools make customization accessible

Results and discussion

Teacher trajectory across three years

As we refined the workshop design, the focus of the teachers' reflections shifted (Figure 2.3). In the first year of the workshop, the most prominent category of teacher reflection was a newfound sense of ownership reflected in the possibility of engaging in customization. In year two, the focus shifted to the use of student work, which aligns with the redesign that provided teachers with student work from their own classroom. Finally, in year three, the focus shifted to the usability of the customization technology, the details of which are beyond the scope of this paper. We analyze the themes of workshop reflections within each category across the three years to connect workshop design features to the customization focus.

Sense of ownership

Ownership emerged as a focus of teacher reflections at the first workshop. The teachers were excited to realize that they could customize the online units. When expressing their sense of ownership after the first workshop, 43% of the 17 teachers present at that workshop wrote that the customization process had enabled them to envision a way to integrate the rest of their successful classroom activities into the online curriculum unit. For example, one teacher wrote that the customization process was "A bit overwhelming also, but very helpful to really make it part of

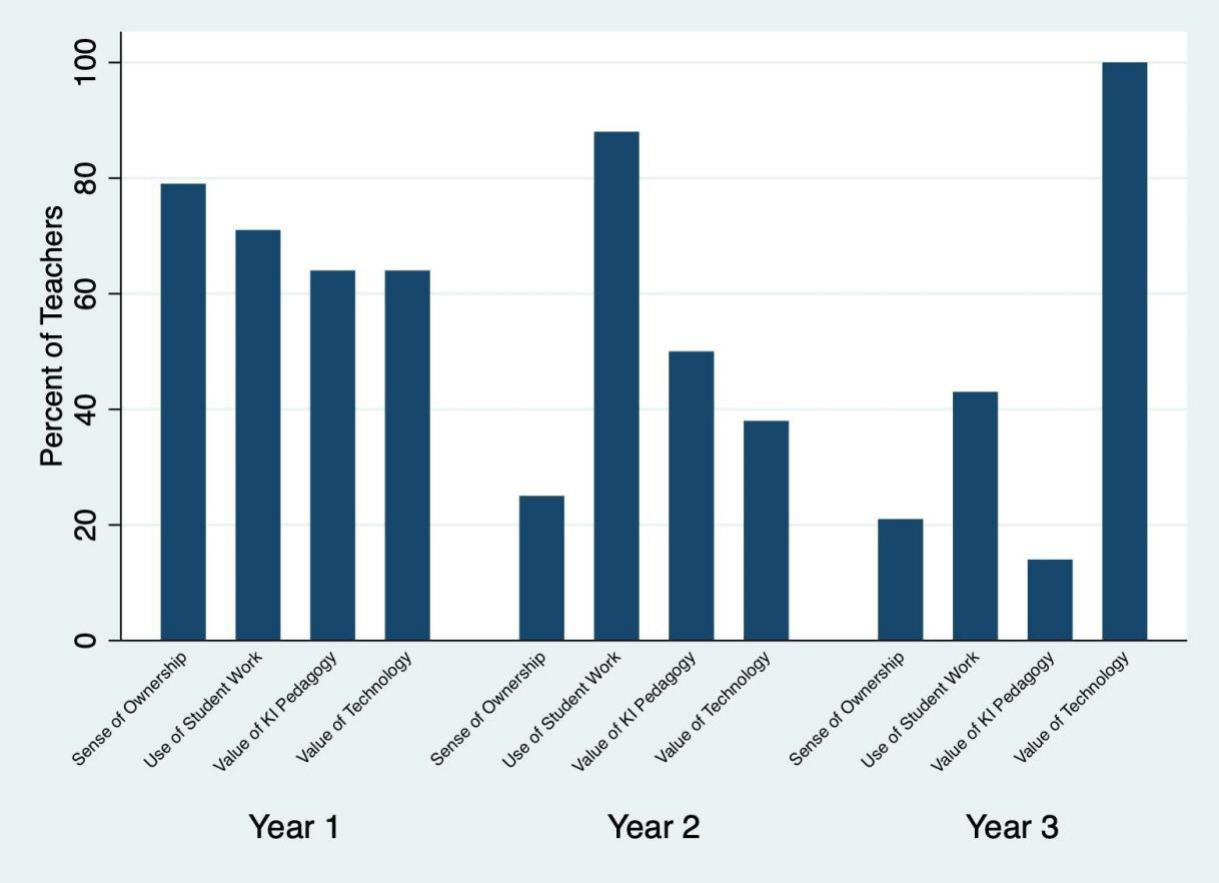


Figure 2.3. Percent of teachers in attendance during each workshop with reflections in each category

the curriculum, intertwined with the actual curriculum, instead of using the WISE projects as separate from the curriculum." Another 33% expressed that engaging in the customization process enabled them to meet their own goals. One teacher wrote, "Yes, this process made it realistic to reach our curricular goals. I liked reflecting on what in the project is addressing what we want and thinking of ways to add offline [activities]." By the second and third years, there were fewer direct mentions of ownership. This decrease most likely reflects the teachers experiences in the preceding workshops. It became less of a novelty to customize online materials.

Value of KI pedagogy

Over the course of the three workshops, teachers shifted the way they spoke about the relevance of KI for their customization process. Knowledge integration was explicitly mentioned the most during the first year of the workshop. This reflects the amount of workshop time dedicated to developing an understanding of the pedagogical framework and the success of the activity where teachers connected the processes to their existing practice. During the first year, nine teachers mentioned insights from knowledge integration in their reflections. Teachers expressed a variety of insights afforded by the activities to make knowledge integration visible. Thirty percent of teachers described KI as useful for clarifying the learning objectives associated with each unit. Thirty percent also said the KI framework provided insight into the design intentions of the unit. Thirty percent also described KI as useful for deciding where and how to make customizations.

In the second and third years of the workshop, fewer teachers mentioned KI directly, consistent with their increased familiarity with KI and how it informs the units. Furthermore, evidence emerged that teachers had internalized the framework into their goal setting processes since half of the mentions of KI during the second year and all of the mentions during the third year consisted of teachers reflecting on how they implemented KI processes in their own practice. For example, one teacher in the second year wrote "I feel my teaching practice is strong in terms of eliciting ideas, good in terms of adding ideas, and fair in terms of reflecting. I would really like to work on the distinguishing part of the cycle" and another said, "I appreciate time to reflect on my practice and how to be more effective. Rarely do you get a chance during the year to think so deeply about the exact steps of how students connect new information to what they already know."

Thus, the workshop activities supported teachers to reflect on how their own pedagogy interacts with the pedagogy of the units and consider how to improve the units to facilitate student knowledge integration. As teachers considered the KI process of the activities in the units and the activities they were adding, they were supported to reflect on the types of thinking they were asking students to do in their own activities. Prior research shows that teachers typically neglect providing students with opportunities to distinguish among their ideas (Wiley, et al., 2019). By increasing teacher awareness of how their own classroom practices can engage each of the KI processes and supporting teachers to visualize the pedagogical design intention for each activity in the unit, the teachers were better able to evaluate their own practice using the pedagogy. As one researcher overheard during a workshop, a group of teachers exclaimed "We need more green [color of distinguishing activities]!" when evaluating their unit customizations.

Teacher use of student work

Across the three workshops, we refined the activities to guide teacher engagement with student work, increasing access to the specific student work generated in each teacher's own classroom. Teachers shifted how they discussed the relevance and utility of student work for informing their customizations as the workshops progressed. These shifts corresponded with the changes in how we engaged teachers with student work during the workshop. While only one teacher mentioned the use of student work during the first workshop, student work was the most prominent category during the second workshop. This prominence corresponds with our change to showing teachers student work from their own students and introducing learning analytics to provide each teacher with a summary of the ideas in their class. In year two, 55% of teachers found the summaries of student work to be helpful for identifying areas where students were struggling or for identifying misconceptions. This is notable given the open-ended nature of the reflection questions and teachers' specific focus on understanding their students' struggles. One teacher reflected, "Students are struggling to incorporate evidence from models in their explanations." A smaller percentage of teachers (22% each) mentioned in their reflections that analyzing student work was useful for identifying productive student ideas to build on or expressed a direct connection between the ideas in their students' work and their plans for how to customize.

By year three, we were excited to note, teachers' reflections shifted away from identifying incorrect ideas towards using student work to find productive ideas to build on to help students develop more integrated perspectives. The majority of teachers' reflections on student work (86%) expressed a connection between the ideas they saw and the customizations they were planning. The remaining 14% said they found ideas to build on. For example, one teacher wrote, "I love the reflective time and the strategies you teach me to become a wiser user of my student responses/data. I also love the ways you present for thinking about teaching to the needs of my

students. I think being able to customize the units to address my preconceptions in student knowledge integration and/or ways of teaching will empower my students to become stronger explainers and reasoners." Another teacher reflected, "due to the sorting activity, I was able to recognize the gaps in student achievement, which spurred me to create scaffolds and re-plan steps for the unit." This shift towards viewing student ideas as productive was more pronounced as the teachers had the opportunity to review their class summary during instruction and to use it for in-the-moment teaching customizations. When they saw it again during the workshop, they were able to reflect on their customization goals. This reaction is consistent with the multiple opportunities to reflect on the same student work. It also aligns with the opportunity to use the class summary during instruction to incorporate the classroom context as teachers got started on building on students' ideas.

Limitations

One of the limitations of this study is the self-report nature of the data used in our analysis. While these data provide important insight into the teachers' perceptions of what was important to them while they were making customizations to the curriculum, they do not capture the substance of teacher customizations or changes in practice. Forthcoming work will examine case studies of teachers' customizations and rationales for their customizations as well as impacts of the customizations on student learning.

Conclusions

We iteratively designed a professional development workshop intended to support customization by making the pedagogy behind our curriculum visible and engaging teachers in analysis of their students' work. We found that the activities designed to make KI visible were initially successful and, as they were improved, became more useful to the teachers. The representation in the first workshop made the instructional goals of each unit explicit and enabled teachers to articulate the connections to their own goals. The move to Google slides and the improvements in the representation provided a more robust view of the KI pedagogy, supported multiple perspectives on the unit, and increased opportunities for teachers to collaborate on customizations. Leveraging a tool that teachers were already familiar with, Google slides, also reduced the complexity of the tool enough to be useable and supportive for the teachers - a critical feature for supports of this kind (Remillard, 2018). Furthermore, refining the representation of the pedagogy strengthened teachers' ability to integrate their own activities into the unit and led to increased sophistication of the reflections on their own pedagogy as they customized the units.

Our methods for making student work accessible increased the likelihood that teachers considered student work as valuable evidence to inform their customizations. This was especially true if the student work was from their own classroom and was directly related to their interactions with students while teaching. This is aligned with other work that suggests the importance of grounding the data we provide to teachers in classroom context (Kerr, 2006). In addition, teachers reported that access to the class summary during instruction enabled them to build on their students' ideas. Further, the combination of the class summary and examples of their students' responses provided teachers with a coherent picture of their students' needs and shifted them away from a deficit view of students' ideas as misconceptions or wrong to a KI view of the value of building on student ideas to encourage coherent understanding.

These results illustrate the challenges and value of careful design of teacher workshops to support teaching customization of curriculum. They show that making the pedagogy visible when

engaging teachers in customizing curricula has the potential to extend beyond the unit being customized. Teachers reported using the KI pedagogy in their own planning and to connect their offline activities to the online curriculum. These results show the benefit of making student work accessible to help teachers incorporate all their students' ideas rather than only those they recollect at the workshop. The added benefit from seeing student data both while teaching and again during PD is consistent suggests that teachers need time to make sense of data about student performance and see its relevance for instruction decision making (Tomanek, Talanquer, & Novodvorsky, 2008).

The results support viewing the customization process as a trajectory. It starts with ensuring that teachers feel ownership of the customization process. It continues by deepening understanding of the pedagogy behind the instructional design so that the participants integrate it into their own pedagogy. It culminates in connecting the pedagogy to the learning activities of the students. In this case, illustrated by a shift from a focus on addressing misconceptions to a focus on building on the nascent ideas developed by the learners.

Chapter 3: Supporting Teacher Development Trajectories for Integrating Social Justice and Science

Introduction

Recently, there has been increased attention to the necessity of supporting science instruction that centers social justice and highlights the political nature of science teaching and learning. Typical science instruction, by neglecting issues of social justice, reproduces social inequities (Dimick, 2012). Integrating social justice requires science teachers to reconceptualize their role and reimagine science teaching as supporting the social, political, and academic empowerment of students (Dimick, 2012; Morales-Doyle, 2017). In doing so, teachers need to attend to the political nature of teaching and the power dynamics, local histories, and issues of justice within the content they teach (Agarwal & Sengupta-Irving, 2019; Madkins & McKinney de Royston, 2019; Morales-Doyle, 2017; Vakil & Higgs; 2019). Teachers continually develop and reformulate these understandings in new teaching contexts (Philip, 2011). This study focuses on the activities of a research-practice partnership called to action by the inequities laid bare as a result of the COVID-19 Pandemic and the increased attention to racial injustice following the murder of George Floyd. We examine the perspectives and trajectories of teachers who were eager but new to designing and teaching curriculum materials that foreground social justice science issues (Morales-Doyle, 2017) in ways that had not been integral to the curricula provided by their schools and districts. These teachers had already been using the Web-based Inquiry Science Environment (WISE) curriculum to complement their other curricula and expressed interest in participating when the WISE RPP began adapting some units to feature social justice issues. This study builds on the findings of Study 1 to examine how the RPP workshop design supports teachers with the goal of integrating and addressing social justice within their science classrooms. I follow the trajectories of three teachers who have been long term members of the RPP who decided to customize units they had previously taught to integrate issues of social justice. In particular, I explore how their perspectives on the relationships between science and social justice, their approaches to customizing science curricula that integrate local social justice issues, and their teaching practices while enacting such units develop over the course of two years. Specifically, I ask the following questions:

- How do teachers shift and develop their perspectives on the relationship between social justice and science over the course of the project?
- How do the RPP activities support teachers to integrate Knowledge Integration Pedagogy and Social Justice Science Pedagogy in their classrooms?

Designing and Teaching for Social Justice in Science

The partnership began with a commitment to center justice in science (Morales-Doyle, 2017) and to promote the integration of the rich ideas each student brings to science class (Linn & Eylon, 2011; Linn & Hsi, 2000). Each partner came to the RPP with different perspectives on what it means to center justice in science and why we should aim to do so. Throughout partnership activities, we have negotiated these perspectives and worked to build towards shared understanding. When beginning the work of developing WISE units that center social justice issues, my aim was to provide students with access to academically rigorous curriculum that centers counter-hegemonic narratives and promotes opportunities to interrogate the political nature

and inequitable impacts of scientific advancement. My perspective was uniformed by a deep body of literature that asserts that education should support students to leverage their community knowledge and resources towards just futures for themselves and their communities (Dimick, 2012; Morales-Doyle, 2017). In this section, I review the literature that informed my stance and the initial design of the units. More information about how we structured opportunities for each partner to articulate and negotiate their stance can be found in the section on the ARISE RPP.

One productive avenue towards achieving social justice science curriculum is to ground traditional science teaching in local social justice science issues (Morales-Doyle, 2017). Many have argued that students can learn state required disciplinary content through learning tasks that engage students in political struggle and address issues of injustice in their local communities (e.g., Barton & Tan, 2010; Barton & Tan, 2020; Buxton, 2010; Corburn, 2005; Dimick, 2012; Morales-Doyle, 2017). Morales-Doyle (2017) clarifies that social justice science issues go beyond the exploration of local, socioscientific or "real-world" issues because they "cannot be understood or addressed apart from understanding and addressing oppression." (p. 1036). Addressing such issues necessitates that both students and teachers learn about the historical and political intersections with traditional science content.

Integrating social justice into science courses provides opportunities for students to make sense of issues impacting their own communities and raises issues around inequality and racism (Morales-Doyle, Childress Price, & Chappell, 2019). Students might combine typical science ideas that help them interpret how an environmental phenomenon impacts people with social justice ideas that help them determine why the impacts are different across racial groups. Developing such science units can involve a lengthy design and iterative refinement process because it requires attention to existing curriculum standards and demands nuanced depictions of social justice issues (Kraig-Turner, 2016; Marks-Block, 2011). For example, Morales-Doyle (2017) reports on a chemistry unit that supported students to succeed academically and learn standards-aligned content while also identifying instances of environmental racism and seeking ways to enact positive change for their community. In this unit the teacher cultivated critical consciousness by supporting students to examine the role of environmental racism while studying pollution from a coal power plant and positioned students as transformative intellectuals by having students present the findings from their investigations at an event with both community members and EPA officials (Morales-Doyle, 2017).

Students often perceive the salience of race when examining data, whether or not teachers take up race or racial discrimination as an important factor for making sense of data (Philip, Olivares-Pasillas, Rocha, 2016). Interactive models can help students explore the disproportionate, negative impact of these environmental phenomena on marginalized communities. They can support students to investigate ways that communities have taken action to disrupt injustices and help students envision solutions needed for change (e.g., Morales-Doyle, Childress Price & Chappell, 2019). Students can interact with visualizations, explore how the factors play out in their local neighborhoods, and connect community dilemmas to historical events. Students can draw on the visualizations to jointly form and debate conjectures about what is happening and why.

In this study, we combined social justice science pedagogy (SJSP; Morales-Doyle, 2017), which grew out of Culturally Relevant Pedagogy (Ladson-Billings, 1995, 2009) and critical pedagogy (Freire, 1970), with Knowledge Integration (KI) design principles (Linn & Eylon, 2011), which grew out of constructivist theory (e.g., Inhelder & Piaget, 1958). SJSP highlights the importance of grounding science instruction in issues that cannot be understood without

interrogating and challenging systems of oppression and positioning students as transformative intellectuals (Morales-Doyle, 2017). KI centers making science accessible, making thinking visible, helping students learn from others, and promoting autonomy and lifelong learning (Linn, Eylon & Davis, 2004). Taken together, these frameworks inform the design of our units, the curriculum customization process, and the assessment of student learning.

Guided by these design principles, the units support students to identify and understand the factors contributing to inequities and to generate strategies for effecting social change in their communities. We began by surfacing social justice science issues, focused instruction on taking action (Morales-Doyle, 2017), and centered one unit on racially disparate health effects of particulate matter pollution and the other on high temperatures in communities local to the participating schools. To design instruction that supports students to connect their ideas encompassing science and environmental racism we drew on KI to design and sequence the learning activities. KI articulates four research-based pedagogical moves for guiding students to develop integrated understanding: *elicit* student ideas and experiences, provide opportunities to *discover* new perspectives, *distinguish* among their ideas, and *form connections* among ideas. (Linn & Eylon, 2011). Taken together, SJSP and KI instructional design should support science teachers to elicit all their students' ideas, to value each students' views, to provide opportunities to discover evidence in relevant and meaningful contexts, to help students distinguish among their ideas about societal inequities, and to reflect on ways to use their insights to advocate for actions that create a just world. While SJSP provides strategies for incorporating the political nature of science, KI provides a framework to design and assess instruction that guides students to link ideas concerned with race, power, and history with ideas from typical science instruction.

Drawing on these frameworks, the units designed by the RPP *elicit* students' observations of the causes and impacts of an environmental hazard (particulate matter pollution and urban heat islands) by drawing on varied forms of evidence including videos illustrating concerns of community groups. The units guide students to *discover* new evidence and perspectives using models and visualizations of local data that enable students to explore connections among core science ideas, and their personal and cultural lives (Polman & Hope, 2014; Rubel, et al., 2016). They prompt students to *distinguish* who in the community is impacted and which factors (policy and environmental) contribute by combining evidence from these sources. The units support students to *form connections* to explain causes and to combine ideas to identify actions that might ameliorate the inequities they unearth. These activities support teachers to introduce issues of environmental racism while suggesting strategies to make each student feel that their questions, concerns, and experiences are welcome and valued in the science lesson and that they are empowered to use science to benefit their community.

Implementing Justice-Oriented Pedagogies

The design of science units that integrate local social justice issues is just one piece of centering justice in science education. To effectively incorporate local justice issues in the science curricula without perpetuating deficit narratives or causing harm, teachers need to develop and enact justice-oriented pedagogies. Studies of inservice and preservice teachers reveal the importance of political clarity to avoid reinforcing racialized power dynamics (Sheth, 2019; Madkins & Nazar, 2022). Since teacher preparation programs rarely address racial bias (Sleeter, 2017) and issues of equity, diversity and justice are neglected in the Next Generation Science Standards (NGSS; Morales-Doyle, Childress Price & Chappell, 2019; Rodriguez, 2015), supporting teachers to develop justice-oriented pedagogy is essential. Brown and Crippen (2017)

took a grounded theory approach to characterize how inservice teachers develop expertise in enacting culturally responsive science pedagogy. Their study revealed that teachers were most successful when identifying science topics relevant to their students' lives, taking an asset-oriented view on students, positioning students as authorities in the classroom, and building community (Brown & Crippen, 2017). We seek to build on these accounts by documenting the experiences and challenges of experienced science teachers who are eager but new to addressing racial justice in their science classroom, as they customize and enact a unit featuring an issue of environmental racism.

Research on science teacher professional development suggests that customization of high quality curriculum materials can be effective for teacher learning (Ball & Cohen, 1996; Gerard, et al., 2011; Remillard, 2000) particularly when analysis of student work is used as evidence to inform customization decisions (Gerard, Spitulnik, & Linn, 2010; Gerard, et al., 201; Tomanek, Talanquer, & Novodvorsky, 2008). In this study, we use the KI model of professional development (Bichler, et al., 2021; see Chapter 2 for design principles) that includes teacher curriculum customization and analysis of student work to design the partnership professional development activities. Given the impact of customization and co-design on teacher learning, we anticipate such activities might shape teacher perspectives on the role of social justice in science, afford science teachers the opportunity to deepen their understanding of locally relevant science topics that connect to the history of systemic racism, deepen teacher awareness of their students' ideas, and support the integration of KI and SJSP teaching practices.

Pilot Study

The present study builds on a pilot study (Bradford et al., 2023) that was conducted with two other middle school science teachers in the RPP: Sam, an 8th grade science teacher who identifies as White, and Alex, a 7th grade science teacher who identifies as Latinx. I will briefly summarize the findings from pilot study that motivated and framed the investigations presented in this chapter. The pilot study reports on the co-design process and teaching that foregrounded a new focus on social justice within the larger RPP. Our co-design activities led to the design of a unit focused on combustion reactions, the health impacts of the products of combustion, analysis of the racially disparate rates of asthma in their community, and comparison of historical redlining maps to maps displaying concentrations of pollution from combustion. This co-design unit served as a prototype that inspired the units taught by the teachers in this study.

While both teachers in the pilot study were eager to integrate a social justice issue into their science teaching using the unit we designed, the two teachers came to the project with different orientations. Sam had spent the summer prior to the study reading about race in the United States and wanted to specifically address the role of racism in science with his class. Alex was focused on making the topic more relevant for his students and also felt that raising justice issues justifiably fit within the Next Generation Science Standards associated with "Human Impacts." That is, Sam thought of racism in science as part of the content that needed to be taught in his class, whereas Alex primarily saw social justice as a tool to leverage engagement in other science content. Further divergence emerged when interviewing these teachers after teaching the unit. Both expressed uncertainty and discomfort around discussing race and racial justice with their students. Ultimately, Sam decided to directly address race and make clear that discussing racism would be an expectation in their class:

> *"I just kind of came out and said it. I'm like it's going to be a part of this class to understand how racism has been affected and somewhat influenced by some people*

in science and it's important for us to address that … I do think that by addressing racism and making it something you speak about... I think it makes it safer to have students feel that you understand and have empathy for them."

Sam still wasn't sure if this was the best approach as this was new to him, but voiced in an email communication that he thought it was better to try it out and learn how to do it better next time rather than waiting to figure out a perfect approach. Alex, on the other hand, opted to side-step race:

"So yeah, there is race in there [the unit]. And I think I pivoted away from that as much as I could, because I didn't want this to become something of, you know, like a race discussion…So just talking about different groups in the community. And then yeah, naming those groups, by ethnicity, you know, the African American group, the Hispanic group, or Latin American group, I think that facilitated, you know, this entry point into some disparities that we see."

When probed further, Alex felt unable to express more clearly why he felt more comfortable discussing the impacts on different ethnic groups than he did discussing racism or using the word race. Alex later added that he was concerned about creating emotional discomfort for his students by talking about race directly. Not surprisingly, we found that Sam's students were more likely to include race in their explanations of the impact of pollution from combustion than Alex's students were. The differences in the teachers' approach could be related to a variety of factors: prior preparation, administrative support, the life experiences of their students, and their own positionalities. For example, as a White teacher, Sam might have felt more secure in his position and the likelihood that he would be perceived as using his privilege to advocate for change, while, Alex as a Latinx teacher might have felt more precarity and an awareness that his centering of race might be perceived as political or "playing the race card". The differences that emerged in teachers' views on the relationship between race and science, despite similar desire to teach the unit, motivated my investigation in the present study on the *development and shifts* in perspectives and in teaching practices of teachers who are eager but new to integrating issues of racial justice into their science teaching.

The ARISE Research Practice Partnership

The Anti-racism Interactive Science Education (ARISE) RPP is a subset of the larger WISE RPP (see Chapter 1 for more information) that is focused on integrating social justice issues in the NGSS-aligned science curriculum. The partnership was initiated when one of the teachers in the WISE RPP, who participated in the pilot study described above, approached some of the researchers wondering if we had resources or ideas to help modify a unit about global climate change so that it addressed how CO2 emissions and air pollution affect BIPOC communities more adversely that predominantly White communities. At the same time, the research team had begun exploring ways to integrate issues of racial and environmental justice into our existing curricula. We partnered with this teacher and their colleague to design and pilot test the first prototype unit in the Fall of 2020 (Bradford et al., 2023). After piloting the unit, we expanded the partnership by inviting other teachers who had previously been a part of the WISE RPP who were interested in integrating justice issues into their science teaching. We also sought out research advisors who

have expertise in social justice. At present, the partnership consists of more than 20 middle and high school science teachers, three research advisors, graduate and undergraduate learning sciences students, computer scientists, and learning sciences faculty. Collectively, we have designed and refined five units: Global Climate Change and Urban Heat Islands; Chemical Reactions, Air Quality and Asthma; Covid-19 and Data Science and Equity; Genetics, Cell Division, and Henrietta Lacks; and Photosynthesis and Food Justice. Each of these units is designed to target different grade levels and NGSS standards.

The ARISE RPP gathers twice a year for 1-2 day workshops that are focused on establishing and maintaining shared commitments to integrating social justice into science; reflecting on our own identities and positionalities and those of our students, particularly as they relate to the issues brought up in each unit; sharing strategies and problems of practice across teachers and schools; reflecting on student work from past years of teaching; and revising the units. There are three key activity types that we leverage in the workshops (Gerard et al., 2022). Positioning activities support all partners to develop or articulate their position about teaching social justice in science, including developing trust with one another and co-constructing criteria for effective instruction. See Gerard et al., 2022 for a detailed description of how these activities support teachers to surface their own perspectives, engage with perspectives of other partners, and build towards shared understanding. Envisioning activities involve role-playing classroom enactment to envision student reactions with trusted partners who have unique classroom experiences. Teachers explore dilemmas such as how to discuss emotional issues in the science classroom. Customizing activities focus on localizing the units to student lived experience and to respond to evidence of student thinking from prior instruction.

This study focuses on three of partner teachers and their students: David, a high school biology teacher who identifies as White; Mary, a high school biology teacher who identifies as Hispanic; and Rosie, a 7th grade science teacher who identifies as White. David and Mary are colleagues at the same school. All teachers teach at racially, ethnically, and linguistically diverse schools (see Table 3.1).

Table 3.1. Participant information

Teacher	School	Demographic Information	Unit Taught
David	A	42% White, 29% Hispanic, 15% AAPI, 13% 2+ Races, 2% Black 22% Free/Reduced Lunch	9th Grade: Global Climate Change & Urban Heat Islands
Mary			
Rosie	B	32% AAPI, 31% White, 18% 2+ Races, 15% Hispanic, 4% Black 18% Free/Reduced Lunch	7th Grade: Chemical Reactions, Air Quality and Asthma

David joined the WISE partnership while he was still pursuing his teaching credential. He used the WISE curriculum while student teaching and participated in research projects with the group. After earning his credential, he began teaching at School A and occasionally taught WISE units in his classroom. He also completed a summer research internship for classroom teachers with the WISE group during the summer of 2019. Starting in the 2019-2020 school year, David began teaching the WISE Global Climate Change unit. When we began the ARISE partnership,

he expressed interest in teaching a justice oriented version of the unit and began attending ARISE workshops. At the time of this study, he had been teaching for eight years and was the chair of the science department at School A.

Mary also teaches at School A, and joined the WISE partnership when her school switched to remote learning due to the Covid-19 pandemic. She was looking for ways to engage her student in inquiry remotely and began using the WISE curriculum at the recommendation of her colleague, David. Since that time, Mary has participated in all WISE and ARISE workshops and taught at least two units in her classroom per year. In addition to joining the ARISE partnership, Mary pursued opportunities with other universities and organizations to design justice-centered science curricula. At the time of this study, Mary had been teaching science for nearly 25 years, with 20 of those years spent at School A.

Rosie was one of the earliest members of the WISE RPP. At the time of this study she had been a part of the partnership for 13 years. Like David, she was eager to explore the aims of the ARISE RPP when we began it. She typically taught several WISE units a year, including the Chemical Reactions unit. She was very interested in helping us adapt the unit so that it had an environmental justice lens and featured an exploration of the impact of a refinery nearby her school, School B. When we began the study, Rosie had been teaching middle school science for over 25 years.

Methods

Curricula, Technology, and Teacher Professional Development

This partnership takes advantage of the Web-based Inquiry Science Environment (WISE) platform, an open source authoring and customization environment, designed to support KI pedagogy. The WISE platform enables both researchers and teachers to quickly and easily customize the units used in the study. Students use the WISE platform to engage in the units and the platform logs all their work, making it easy for teachers to assess student progress and offer real time feedback to students.

Global Climate Change and Urban Heat Islands Unit

David and Mary both taught the Global Climate Change and Urban Heat Islands unit (UHI unit) to their 9th grade biology students in the spring of 2022 and spring of 2023. In both years, David and Mary taught the unit over the course of 7 50-minute class periods. This unit was developed by building on the existing WISE unit about Global Climate Change to integrate lessons about Urban Heat Islands, redlining, and the health consequences of high temperatures. Both David and Mary interleaved warm-up and homework activities in between activities in the UHI unit and had their students complete the unit individually. This unit features interactive models, data visualizations, and mapping activities. Students first explore how energy from the Sun is transferred and transformed to heat the Earth. They use interactive models to develop understanding of the natural greenhouse effect and then investigate how human activities can amplify the greenhouse effect leading to anthropogenic climate change. Students are then prompted to consider the impact climate change has on people. They are introduced to a number of youth climate activists from their community and are asked to consider whether all people experience the impacts of climate change the same amount. Students explore the Urban Heat Island phenomenon through investigations of how different surfaces are heated by the sun (Figure 1). Students deepen their understanding of the UHI phenomenon by distinguishing how historical,

racist policies, like redlining, contribute to some areas becoming UHIs. Students compare historical redlining maps to present day temperature maps to gather evidence of the impact of redlining.

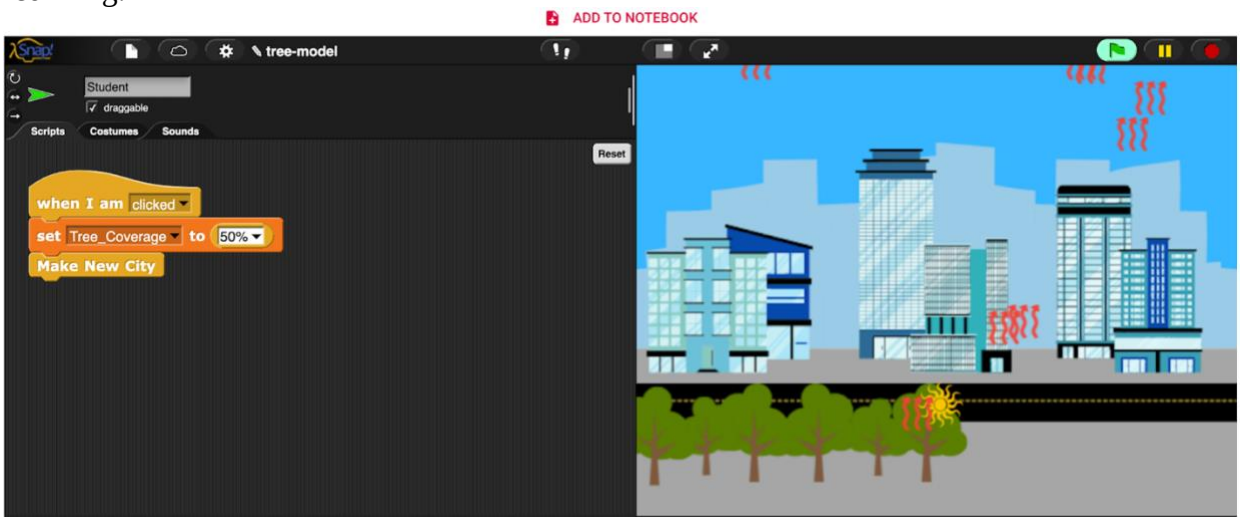


Figure 1. Example activity from the UHI unit where students investigate how surfaces and features in a community affect temperature.

Chemical Reactions, Air Quality, and Asthma Unit

Rosie taught the Chemical Reactions, Air Quality and Asthma unit (Asthma Unit) to her 7th grade science students in spring 2022 and in spring 2023. Rosie taught the unit over the course of two weeks in both years of teaching. The Asthma Unit was built by integrating lessons about incomplete combustion, particulate matter pollution, and racially disparate rates of asthma hospitalization. Rosie interleaved additional resources, class discussions in between the activities of the Asthma unit. She had students complete the unit in pairs. This looked like students discussing each activity together and then taking turns each day for which partner recorded the pairs' responses on the WISE platform. In the unit, students use interactive models to explore the reactants and products in a gasoline combustion reaction. They are prompted to consider the products of an incomplete combustion reaction, which happens if the reaction occurs with too little oxygen, a common occurrence leading to high levels of particulate matter pollution near refineries, along railways, and by freeways transporting large diesel trucks. Students are then introduced to activists from a nearby community located next to a local refinery who object to the refinery's impact on residents' health. Students analyze asthma hospitalization data from the community that has been disaggregated by race to uncover racially disparate rates of asthma hospitalization. Students then compare maps of particulate matter pollution to historical redlining maps to gather evidence of how housing segregation contributed to the racially disparate asthma hospitalization rates (Figure 2). They examine the impact of regulations enforced as a result of activists' efforts and propose their own solutions that connect their understanding of combustion reactions to the history of racial injustice in the community.

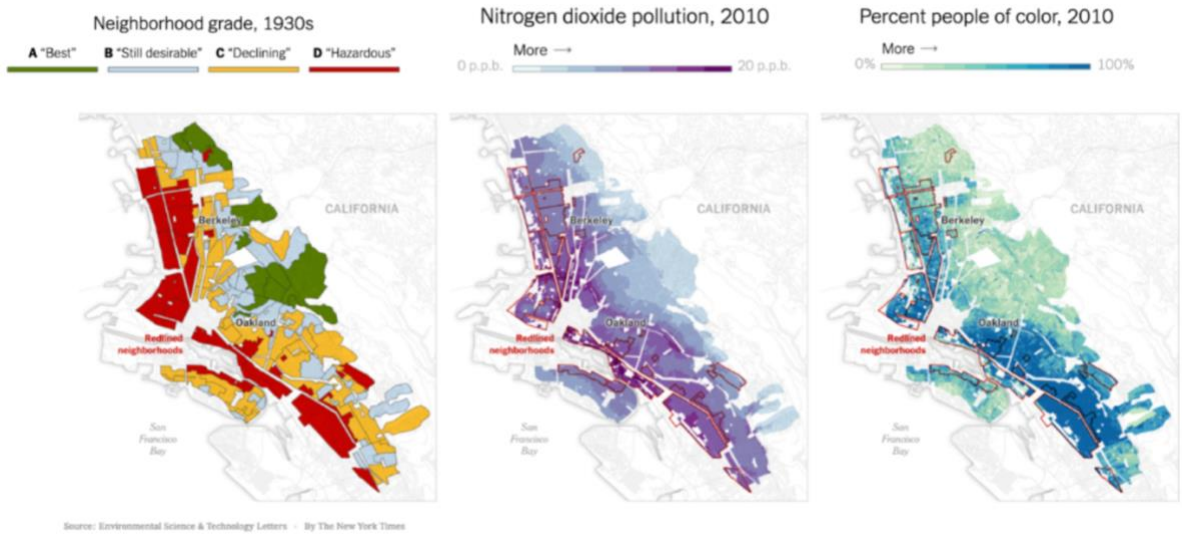


Figure 2. An example activity from the Asthma unit where students use maps from a New York Times article to investigate the relationship between historical redlining, air pollution, and racially disparate rates of asthma hospitalization.

Partnership PD Activities

Prior to each round of teaching a unit, each teacher participated in an semi-structured interview for approximately 30 minutes. The interview protocol was designed to elicit the teachers' perspectives on their purpose for teaching a science unit grounded in an environmental and social justice issue. The interview also asked teachers to anticipate how their students would respond to the unit content, both in terms of the ideas they might raise and in terms of the emotions the unit might surface. The interview prompted teachers to consider ways they might customize the initial unit to better suit the needs and context of their students. Any customization suggestions raised during the interview were discussed and collaboratively elaborated during the interview. The researcher made any agreed upon customizations to the unit. Before the second round of implementation, the interview also included questions to promote reflection on the past round of implementation.

In addition to the individualized support provided in the interviews, RPP-wide workshops were planned twice each school year, once during summer break and once during winter break. These workshops were designed following the design principles and activities discussed in Chapter 2. These workshops also featured activities to support teachers to position themselves in this work, envision strategies for supporting their students during the units, and engage in sense-making of the ideas students raised in their written work (Gerard et. al., 2022). Additionally, the workshops featured opportunities for partner teachers to exchange expertise through sharing their experiences, discussing justice-oriented teaching practices, and co-designing curriculum customizations. Partner teachers were not always available to attend workshops.

Data Sources

Teacher Interviews

All teachers were interviewed prior to each round of implementation. Teachers were also interviewed after their second time teaching the units. Teacher interviews were conducted and recorded via Zoom or conducted in person and were audio recorded. Audio files were transcribed for analysis.

Classroom Observations

One researcher was present during every day of classroom instruction for each teacher for at least one class period. David and Mary's classrooms were observed in person, while Rosie's classroom was observed over Zoom during the first year of implementation. To facilitate observations over Zoom, Rosie carried a computer with her while delivering instructions and moved the computer among student table groups to enable the researcher to hear content of student conversations while working on the unit. During the second year of implementation, all classrooms were observed in person. The researcher maintained a running transcript of teacher and student utterances in the classroom by hand transcribing what was said. After each observation, the researcher wrote a memo to make note of moments that seemed relevant to the research questions, such as moments when the teachers made pedagogical moves that addressed the role of race in science, the teachers brought in activities and resources from outside the unit, or expressed personal connections to the unit. The researcher also documented a summary of any casual conversations about student ideas or the unit that were initiated by the teachers between class periods or before or after school, though these data were only used for supporting researcher understanding on the classroom context and not directly compared.

Workshop Artifacts

During the workshops we used the WISE platform to log teachers' written responses to open response prompts. I use the teacher's written comments to supplement understanding of their perspectives and customization plans.

Student Learning

The web-based platform logs students' responses as they engaged with the unit, and we collected the pre/post assessment responses for all students in each teachers' classroom. At the start and the end of both the Asthma unit and UHI unit students are prompted to explain, "Do you think climate change (or the impacts from gasoline combustion, depending on the unit) impacts all people the same amount?" During the unit students gather evidence about how climate change and emissions from combustion impact human health and historical policies motivated by racism and classism that contribute to unequal impacts on particular groups. This question targets students' knowledge integration about the health impacts of combustion emissions or living in areas that are prone to increased heating as global temperatures rise and the social and place-based factors that influence how likely someone is to experience the impacts. It calls for students to link ideas about how proximity to sources of pollution or urban heat islands impacts health and how historically racist policies like redlining influence where pollution sources and urban heat islands are located and where people live.

Data Analysis

Teacher Interviews and workshop artifacts

Teacher interviews and workshop reflections were used to characterize teachers' perspectives about integrating social justice into science teaching and their beliefs about the relationship between social justice and science. Teachers' comments during interviews and their written reflections represent their espoused beliefs and perspectives. Our goal is to put teachers directly expressed commitments in conversation with the choices they make while customizing the units and the practices they employ while teaching the units.

The interviews and workshop artifacts also contain a record of the customizations teachers made to the units in each year and are used to describe the customization choices each teacher made and their rationale for doing so.

Classroom Observations

Analysis began with a round of inductive coding (Saldaña, 2013) to generate an emergent set of themes based on what was observed in the data. The goal of this was to establish a grounded view on the practices and stances that the teachers were taking while enacting the units. I felt this approach was an appropriate starting point as there is limited theorization of how teachers develop the capacity to enact justice-oriented pedagogies. Further, the enactment of such pedagogies using units that center racial justice is highly contextual. To gain a deep understanding of how the teachers in the study developed, I wanted the analysis to be grounded in the teachers' actual experiences that are shaped by their school contexts, identities, and relationships with their students.

From this round of open coding, a list of codes were generated that characterized the practices taken by the teachers. Some of these codes included *pressing for racial clarity*, *reading from the unit*, *elaborating on student voice*, *providing space for all students in the classroom*, and *making personal connections to the unit*. The next step in coding was to generate a set of a priori codes that were informed by both KI pedagogy literature (Linn & Eylon, 2011) and the literature on SJSP (Morales-Doyle, 2017) and other justice centered science pedagogies (e.g. Brown & Crippen, 2017). These codes were taken together to form a cohesive list to revisit the data and apply the codes across all classroom observations.

The next step in refining the coding scheme was to meet with a group of the researchers in the RPP and apply the combined set of a priori and emergent codes to the classroom observation. The research team first reviewed the set of codes to ask clarifying questions and note possible sources of overlap or tension and places where there wasn't clarity in the meaning of the code. Next, we independently tried to apply the codes with the aim of identifying where to clarify the existing codes, suggesting places to collapse codes that were overlapping, and illuminating codes that were missing from the set. This process was done with a justice-foregrounded lesson segment from one teacher's classroom. During this process it emerged that many of the codes that were generated in the round of open coding were overlapping with or subsets of the codes from the literature. This takeaway led to the refinement of the coding scheme, so that emergent practices were categorized within the codes that were generated from the literature. This resonated with me because many of the practices from the literature are described at a high level whereas the codes that emerged from the classroom observations served as more specific and localized examples of enacting such practices.

The coding scheme was revised to feature only the a priori codes with the emergent practices categorized as subcodes. For example, [blah was categorized under blihblah]. Next, the same small group coding process was repeated with the revised coding scheme and a justice-foregrounded lesson from another of the focal teachers, both to clarify the coding scheme and to

check that it was applicable across the focal teachers. The process resulted in a final refinement of the coding scheme elaborating distinctions between several codes and pulling out codes that were not fully captured within the a priori set into a new category of emergent practices that seem to be in service of justice-oriented science instruction. The final coding scheme is in Table 3.2. I then used NVivo qualitative analysis software to apply the final set of codes to the entire corpus of classroom observation data. Only teacher utterances were coded. Each teacher talk turn was considered an utterance and served as the unit of analysis. Utterances could be coded as more than one code. Not all utterances were coded (e.g. comments pertaining to logistics like cleaning out lockers at the end of the school year were not coded).

To analyze patterns from this coding process, we compared the frequency of codes at different times in the project. We looked for the practices that were most common across all teachers. We compared how each teacher's distribution of codes varied from year 1 to year 2.

Additionally, within the observation data for each teacher, we identified cases of one lesson segment where the teacher facilitated discussion of an activity that foregrounded disciplinary concerns (called *disciplinary-foregrounded episode*) and one that foregrounded justice issues (called *justice-foregrounded episode*). We identified cases based on the observations from the first year of teaching and then identified the same moments as cases in the second year of teaching. This was motivated by one of the pilot studies (Bradford & Gerard, 2022) where we found that teachers were less likely to apply their robust pedagogical strategies in justice foregrounded activities than in activities where disciplinary ideas were foregrounded. In particular, we saw that teachers were less likely to use distinguishing questions or to push for connections when discussing justice issues than when the science was foregrounded. Our hypothesis is that we might see an increase in strong pedagogical practices in the second year of teaching. We also sought to determine whether there were practices that were more common for teachers in one context over the other, and to compare that across years.

Table 3.2. Coding Scheme applied to classroom observations.

Codes	Description
SJSP Practices	
Read from unit (emergent)	Teacher directly reads text content from unit
Customize unit (emergent)	Teacher adapts an activity in the unit or interleaves a new activity
Share personal experience	Teacher shares personal experiences that relate to unit content and/or invites students to do the same
Build community connections	Teacher makes comments or structures activities that foster positive relationships among students or with broader school or local community
Center emotions	Teacher shares their emotional reactions to topics discussed and/or invites students to do the same.
Make systems of oppression visible	Teacher supports students to understand and examine evidence of the impact of systems of oppression, like systemic racism, that shape society. This is one aspect of fostering critical consciousness.
Guide students to distinguish feasible solutions	Teacher supports students to see how they can use their knowledge and skill to improve their social reality by positioning students as transformative intellectuals. This is another aspect of fostering critical consciousness.
Position students as intellectual authorities	Teacher acknowledges and values students' contribution of expertise through their own ideas and experiences
Ground learning in SJSI	Teacher frames learning activities around issues that can't be understood without addressing the impact of systems of oppression
Foreground local issues	Teacher situates learning activities in a locally relevant context
Express high academic expectations	Teacher expresses expectation that students are able to develop and express rigorous understanding
KI Practices	
Elicit	Teacher creates opportunities for students to express ideas, prior knowledge, and experiences
Discover	Teacher creates opportunities for students to explore new ideas
Distinguish	Teacher creates opportunities for students to sort among their ideas and determine which hold explanatory power
Reflect/Connect	Teacher creates opportunities for students to reflect on understanding and link together ideas from across their learning experiences.
High-level KI reference	When the teacher speaks generally about the importance of connecting ideas and evidence.

Finally, we computed a crosstabulation of codes associated with KI pedagogy with codes associated with social justice science pedagogy to see which codes overlap most frequently. Our aim with this analysis was to provide a grounded characterization of what bringing together KI and SJSP looks like in the classroom.

Student learning outcomes

We used a pre- and posttest design to examine the impact of the unit and the teachers' implementation choices on student learning. We focus in particular on one assessment item that requires students to connect their understanding of the disciplinary content with their understanding of the social justice issue. We developed a KI rubric (Liu, et al., 2011; Table 3.3) to score student responses to the pre- and posttest assessment question. The rubric enumerates targeted ideas that were generated through a combination of a priori ideas that were introduced in the unit and other ideas that emerged from student responses. The scoring prioritizes links between ideas and does not penalize students if they hold a combination of accurate and inaccurate ideas. The responses are scored on a scale of 1-5. Not all students reached the post-assessment in the class time allotted by the teachers, so those students' work was dropped from the dataset (final N year 1=186, final N year 2 = 151). We examined the ideas expressed by students in the assessment item to understand the impact of the co-designed materials, enactment choices, and perspectives expressed by their teachers. We conducted a two way ANCOVA with posttest score as the dependent variable, pretest score as a covariate, and teacher and year of instruction as independent variables. We conducted this analysis to understand the ways that teachers' practice influence student learning and to examine whether teachers are improving in their ability to support students to integrate ideas about disciplinary mechanisms and social justice issues in their second year of teaching the units.

Table 3.3. KI rubric for pre/post assessment.

Item Prompt: *Do you think climate change (or the impacts from gasoline combustion, depending on the unit) impacts all people the same amount?*		
Target Ideas: Impacts depend on proximity to a source of pollution/low air quality or an urban heat island, different areas experience different impacts, current/historical policies have a role (redlining, or other policy), social factors like race, ethnicity or SES have a role, an individual's health is impacted by exposure to air pollution or high temperatures		
KI Score	Criteria	Example responses
1	No answer; irrelevant; I don't know	idk
2	On topic, but nonnormative: all people are impacted the same; normative but vague (without explanation)	No, not ALL humans are effected by Climate Change in the same way but most are.
3	Partial link: one target idea	Yes, because if you have more freeways or factories where you live you could have more of the effects of incomplete combustion than places without many. If you live near refineries and places with fewer trees you will also be impacted more, though everyone is impacted to some extent..
4	Full link: links two target ideas	I think that people who are lower income are impacted by climate change more than people who aren't. I think this because they sometimes have to live closer to factories and other places where there could be harm.
5	Full links: links three or more target ideas	NO! Racially oppresed groups are affect more by climate change. These groups are in redlined communities which put near industrial areas which produce green house gases. These greenhouse gas emmisions give you a higher chance to have asthma.

Results

Student Learning Outcomes Across Year 1 and Year 2

We used a pre/posttest design in both years of instruction to gauge the impact of the customized units and the teachers' enactment on students' ability to connect their ideas about disciplinary concepts and social justice issues. We leverage changes in student pre to posttest

learning gains as an indicator for the teachers' progress in customizing and teaching the units. Mean pretest and posttest scores for each teacher in each year are shown in Figure 3.3. Across all teachers, paired t-tests indicate that students made statistically significant learning gains in both the first and second year of teaching.

We conducted a two way analysis of covariance (ANCOVA) with posttest score as the dependent variable, pretest score as a covariate, and teacher and year of instruction as independent variables. There was not a significant interaction between year and teacher ($F(2,336)=0.47$, $p=0.623$, $\eta^2 = 0.003$), suggesting that the added experience of each teacher teaching the unit for a second time and participating in RPP activities did not have a differential effect on student learning outcomes by teacher. However, significant main effects for both the year ($F(1,336)=4.35$, $p=0.038$, $\eta^2 =0.013$) and teacher ($F(2,336)=7.39$, $p<0.001$, $\eta^2 =0.043$) were observed. Post-hoc pairwise comparison of posttest means for each teacher and each year were performed using Tukey's HSD. Pairwise comparisons reveal that across all teachers, when controlling for pretest score, students had significantly higher posttest scores in Year 2 than in Year 1.

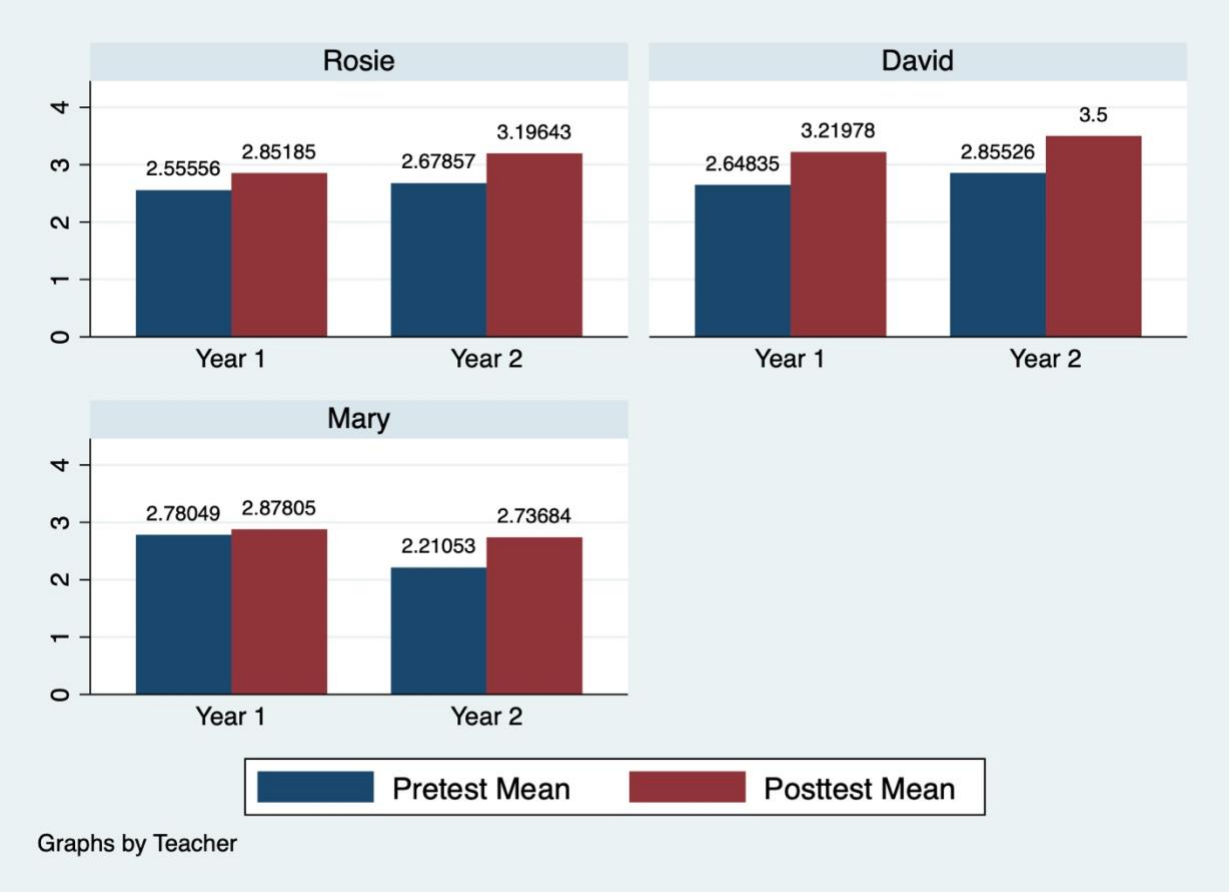


Figure 3.3. Mean pretest and posttest KI scores on the Impacts item from Year 1 and Year 2 for each teacher.

To better understand what supported student learning and why learning gains were greater in the second year, in the sections that follow, we will present cases to characterize and compare each teachers' perspectives and practices over the two years of instruction.

Teacher Perspectives on Integrating Social Justice in Science

To better understand the teachers' perspectives on why social justice should be integrated into science teaching, we examined their responses to interview questions. All of the teachers exhibited some form of shift in their perspective as they continued throughout the two years of the project as indicated in their comments during interviews. Two of the teachers, Mary and David, exhibited deeper connections between their stance and their personal experiences and identities in Year 2 as compared to Year 1. For David, this coincided with a shift in his rationale for why he believed it was important to integrate social justice issues into his science teaching. For Mary, this reflected a stronger articulation of the perspective she shared in Year 1 and an increased clarity or willingness to share the experience that informed her perspective. Rosie exhibited a relatively stable perspective throughout the duration of the project. In Year 2, Rosie made customizations to the unit that reflected a strengthened alignment between her perspective and her teaching practices.

In Table 4, we present a table summarizing each teacher's perspective on the purpose of integrating social justice into science at the start of each year of the project. The table also includes researcher interpretations of any shifts in perspective from Year 1 to Year 2 and examples of instances where the teacher's perspective was reified through their teaching practice. Following the table, we present examples from each case to illustrate the trends presented above and within Table 3.4.

Table 3.4. Summary of each teacher's perspective on why they should teach social justice issues in science during each year, researcher perceptions of any shifts in perspective, and connections between perspective and classroom practice.

Teacher	Perspective Year 1	Perspective Year 2	Shifts	Connections to Practice
Rosie	It is an educator's duty to help students uncover the connections between racist policies in the US and the scientific phenomena studied in science class.	It is part of an educator's job to help students critically interrogate what is going on in the world around them.	Stable/Consistent	More deeply connected perspective to practice in Year 2 by changing the requirements for the final project she assigned.
Mary	It is important to give students and opportunity to learn how historical policies and institutionalized racism impact health outcomes	There are many intersections between systemic racism, historical policies, and present day health outcomes that are important for students to understand.	In Year 2, clarified that her perspective is motivated by her own experiences: earning a PhD in Behavioral Sciences and Public Health, growing up in a low income, immigrant neighborhood in Los Angeles, and observing the experience of her husband and children who are Black Americans.	Shared more of her personal experiences that informed her perspective with researchers and students.
David	Integrating social justice issues would make science content more relevant, particularly for his Latinx students, a growing population in the school district.	Understanding global justice issues is an inherent part of learning fully about science topics like climate change.	In Year 2, shifted from emphasis on relevance to emphasis on connectedness of science and social justice.	Additional time spent facilitating class discussion about climate protests and redlining in Year 2 as compared to Year 1.

David: shifting perspectives through personal connection

David historically taught the WISE global climate in his 9th grade biology class. Prior to the present study, he had spent a lot of time supporting the refinement of the unit, both through workshops and through a summer research internship where he analyzed classroom data. In his initial interview prior to the first year of teaching the newly redesigned unit that emphasized social justice, David shared that he wanted to teach the unit because it would make his science content more relevant, especially to the increasing number of Latinx students at his school, which he argued was a "pocket of students ignored by the district." He reflected that his school was

presumed to be a high performing school with a pretty homogenous population. He noticed that this was changing, but the needs of the students were not really being addressed by the district or school administration. He thought that teaching the UHI unit might help engage more of his students because it makes the science content more relevant.

Prior to teaching the unit a second time, when asked again why he thought it was important to integrate social justice into science, David offered a different perspective than he shared prior to the first year teaching the unit. He expressed an orientation that his students couldn't really learn deeply about issues like climate change if they didn't also learn about the entangled justice issues. He offered that climate change is such a rich issue that there are many ways you can approach teaching it that are in line with the state standards. He felt this gave him an entry point to center social justice issues and teach science in a way that was aligned to the reality experienced by his students. He shared, "You can't just separate [climate change] into here's the content you're supposed to learn and here's this global issue. It's all one thing." The departure from an emphasis on relevance to a stance that reflects that justice issues are inherently a part of science suggests that David's perspective on why justice belongs in science was becoming more integrated. Further, he shifted from thinking that a focus on social justice issues would be relevant for just the Latinx students in his class to recognizing the importance of engaging all students in making sense of such issues.

There are many possible explanations for what brought about this shift in David's perspective. His experience of teaching the unit for the first time and engaging in conversation with his students likely contributed. His comments during the workshop following his first time teaching the unit might also provide insight into how his thinking evolved while participating in the project. During the summer workshop, one activity, which we call the *positioning activity*, was structured to support teachers to reflect on their relationships with their students, and to consider how their own history and their students' histories shape the way they are engaging with the content in the unit. After engaging in the *positioning activity*, David reflected that while teaching he often felt, as a White man, it was "not [his] place" to raise racial equity issues but recognized that he needed to spend more time considering how his own history and his students' experiences interact with redlining in order to best serve his students and truly make visible "the intersection of science and reality." But after his first year of teaching, and during our first workshop, he shared that he had begun to reflect on his own positionality as a White man and his role in raising awareness around racial equity. He expressed a commitment to learning more about how his own history and his students' history might make visible this intersection of science and reality.

Mary: connecting perspective to personal experience

When Mary began the partnership under study in this chapter, she had already been participating in the larger RPP for several years. She had also already spent considerable time seeking out opportunities to integrate social justice in her science teaching. For example, she had participated in a summer program at another institution where she designed other justice-centered learning opportunities for her students. She reflected that pursuing these opportunities was part of her commitment to support her students to develop the skills that they needed to be civically engaged and to provide purpose for their science education. Her stance and commitment to integrating science and social justice was consistent throughout her participation in the partnership. Mary had historically taught the WISE global climate change unit and was eager to switch to teaching the version that integrated social justice through an examination of urban heat islands and

the legacy of redlining in her school's local community. During her interview prior to teaching in Year 1, she expressed that she felt this switch was a key learning opportunity for their students:

> "I think it's an important issue that students need to be aware of, you know, this whole institutionalized racism has shaped history and impacted people's health. I mean, just historically, and it's happening today still, right? So I think it's just something important to bring to their minds. And sometimes people don't even think about the wider impact, you know, of these old laws and ways of doing things and the repercussions are still happening now."

In the interview prior to beginning teaching in year two, she expressed similar sentiments saying, "I think with this heat island one, I think it's really good. I remember thinking last year, oh, that really ties everything back around, you know, in terms of access to health care, again, because you're experiencing these health issues." During this interview, Mary also began to express more personal connections and was willing to share some of her own life experiences that informed her stance and her knowledge about the topics that she shared in the classroom. For example, Mary shared more information about her academic background that supported her understanding of the intersections between social justice and science and informed the approach to teaching the unit:

> "So, I have a PhD in Behavioral Sciences and Health Education, so I spent a lot of time thinking about social equity and health. And so not that it comes naturally, but because of, I mean, I studied this for years. I can see that the issues of access to care are huge. You know, just so, just my perspective of thinking about health and science. It just naturally blends together because of an academic sort of practical background in dealing with health."

Mary shared that much of her perspective has been informed by her academic career and development. Sharing these experiences helps to explain why racially disparate healthcare access and health outcomes have served as a productive entry point for integrating social justice into her science classroom. Further, understanding that Mary had devoted years to advanced study of health equity helps clarify why teaching social justice issues is important to her and her preparation to have sufficient content knowledge to engage her students in learning about such issues.

Mary further elaborated that it was not just her academic preparation that motivated her belief in why it was so important to teach her science students about social justice issues. She shared that her lived experiences and those of her family also shaped her perspective and informed her understanding:

> "You know, I mean, I'm Brown, and you know, grew up in the hood, I mean, really, like in a poor you know, predominantly Spanish speaking neighborhood in Los Angeles… by the docks in Wilmington, so, like really poor air quality and stuff, and, you know, it's a lot of imagine many, there's a number of different immigrant communities there and just lack of access to care, you know, so that those types of things. And then, my husband is a Black American. So his family's experience, you know, of prejudice, inequality, just on a daily basis, right. So, I guess it's lived experience."

There are many ways to interpret Mary's willingness to share about her personal experiences as they pertain to the unit and her perspective on why and how to teach it. It might suggest a deepening connection between her perspective on teaching and her own personal commitments. It might also be indicative of growing trust throughout sustained cooperation during the partnership, and the establishment of shared commitments within the RPP leading to a greater willingness to share. A further possible explanation could be the success she found when sharing her personal experiences with students while teaching the unit in the first year. For example, when holding a discussion with students about who is likely to live in UHIs and experience both the health and economic consequences of living in a UHI, she shared with students about her experiences growing up, saying: "In my experience, I grew up in a multigenerational household, like traditional Mexican household, and these elderly grandparents and great grandparents live in the house with [you]." She shared her experiences to help students think more concretely about the people who might live in UHIs and what that experience might be like. Students responded positively to her sharing and it spurred further discussion of what it's like to live in such a household and the strategies families would take to cope with increased temperatures. Mary chose to share about this personal experience again while teaching during the second year.

Rosie: connecting perspective to practice through customization

Unlike David and, to a lesser extent, Mary, Rosie exhibited a relatively stable perspective throughout her participation in the project. Prior to participating in this study, Rosie typically taught the WISE chemical reactions unit with her seventh grade science students. She had contributed to the co-design and refinement of the unit throughout other research studies in the RPP prior to adopting a focus on integrating social justice issues. During a workshop prior to the beginning of the present study, Rosie indicated that she was interested in teaching the new justice-centered version of the unit. She expressed that she believed it was important to link the disciplinary content of the Chemical Reactions unit to the racially disparate asthma rates and legacy of redlining in their local area. She shared the perspective that "Our country is running on racist policies, and as educators it's our duty to help combat this. As science teachers, it is our duty to point out the connections between these racist policies and the scientific phenomena we are learning about." This stance was consistent for Rosie throughout her participation in the project, noting similar ideas between rounds of implementation and after the second year teaching. After the second year of teaching, we asked Rosie again to reflect on the purpose of integrating social justice into science. She shared, "like this is what's happening in our world right now. It's a big problem. Where else are they going to learn this stuff? So it's our job as educators." As we can see, Rosie maintained a consistent sense of duty as an educator to use their class time to help their students learn about issues in society.

Looking more closely at the ways Rosie customized the unit and her enactment of the practices, we can see how her stance towards integrating justice in the science unit showed up in her actions over time throughout the project. The first year teaching the unit, Rosie made a number of customizations to adapt the project to better meet the needs of her students and to achieve her goals for integrating social justice into the science classroom. One of the major customizations that Rosie made was to design a final project for the unit that had students engaged in creating a "Call to Action" project where students selected a topic related to the unit and created a visual to raise awareness and call for action in their communities. The goal for the project was to support students to connect the understanding they developed during the unit to actions their community

could take to address the harms that they had investigated. Despite this emphasis, as we further broke down the details of the project, Rosie decided to include an option for students where they could choose to focus their call to action assignment project on individual actions to reduce contributions to climate change, like walking to school or remembering to turn off the lights. She expressed that she included this option to ensure there was an option for students who were either uncomfortable with the justice aspect of the project, or for their parents in case she got pushback that she was forcing students to engage with content that was political in nature:

> "So one of the things that I'm trying to do here is to provide an outlet for let's just say, I don't think I'm gonna come across it, but let's just say I have a kid and a family who are like you're shoving this down our throats. It would be nice to have an option that's a little bit more bland. So like that kid could choose the you know, individual actions kind of choice and that's fine."

While the other final project choices "push a bit more into the inequities", as Rosie put it, than a focus on individual actions, Rosie wanted to create a project that was comfortable for all students.

After teaching the unit for the first time, Rosie had additional ideas about how to customize the unit to address some of the concerns she had following the first year teaching. For example, one worry she had was that a lot of students ended up picking fairly surface level "Call to Action" projects, where they did not engage deeply with the justice issues that they explored during the unit. She noted that, despite hearing students discuss inequitable distribution of exposure to air pollution and racist housing policies as root causes for the racially disparate rates of asthma hospitalization in their area, she found that students still tended to pick projects focused around individual actions that could be taken to mitigate contributions to climate change. Rosie believed students made this choice because it was easier for them to talk about things that they know and that they've heard about time and again in school.

Rosie felt that many student projects did not sufficiently illustrate either the science or the justice concepts that students talked about during the unit. In response, Rosie revised the final project in the second year by removing the option to focus on individual actions so that all the project options were connected to the justice issues. This customization indicates a deepening of the alignment between Rosie's stance and her practice. By refining the requirements of the final project, Rosie's actions communicate a strengthening ability to teach that science and justice are inherently connected, and the view that it is a disservice to students to allow them to pick them apart and only focus on science ideas they are more comfortable with. This choice brings her teaching practice into closer alignment with her perspective that it is part of her responsibility as a teacher to help students learn the connections between racist policies and the science they learn. For Rosie, reflecting on whether the assessments she designed supported students to express an integrated understanding of science and justice concepts supported her to better align her assessments to her aims in the second year of teaching.

Teacher Practices for Integrating Social Justice into Science

We observed each teacher for at least one class period per day as they taught either the UHI or Asthma unit during both years of the project. Based on the observations, we noticed which SJSP and KI-aligned practices each teacher employed to integrate social justice issues into their science teaching. There were shifts in how frequently teachers employed each from Year 1 to Year 2 (see Figure 3.4). Tables with the frequency of each code for each teacher during each year can be found

in Appendix A. Throughout this section, any teaching practices that were a part of the coding scheme are denoted by a change of `font style`. Looking across the years, three patterns emerged as we examined the change in frequency of each code from Year 1 to Year 2 and as we examined which codes tended to co-occur. We observed that teachers `elicited` their students' ideas and experiences more frequently during Year 2 as compared to Year 1. We also noticed that teachers engaged in the practice of `building classroom community` more often in the second year of teaching. Finally we observed that teachers' practices to foster critical consciousness, `making systems of oppression visible` and `guiding students to distinguish actionable solutions` most frequently co-occurred with KI practices and increased differentially by teacher in Year 2. We also observed that the KI practice `distinguish` frequently co-occurred with practices geared towards making systems of oppression visible. In the sections that follow, we discuss each of the patterns in detail. We compare the shifts each teacher demonstrated and provide a grounded description of what it looked like for them to integrate SJSP and KI pedagogy over the two years of the project.

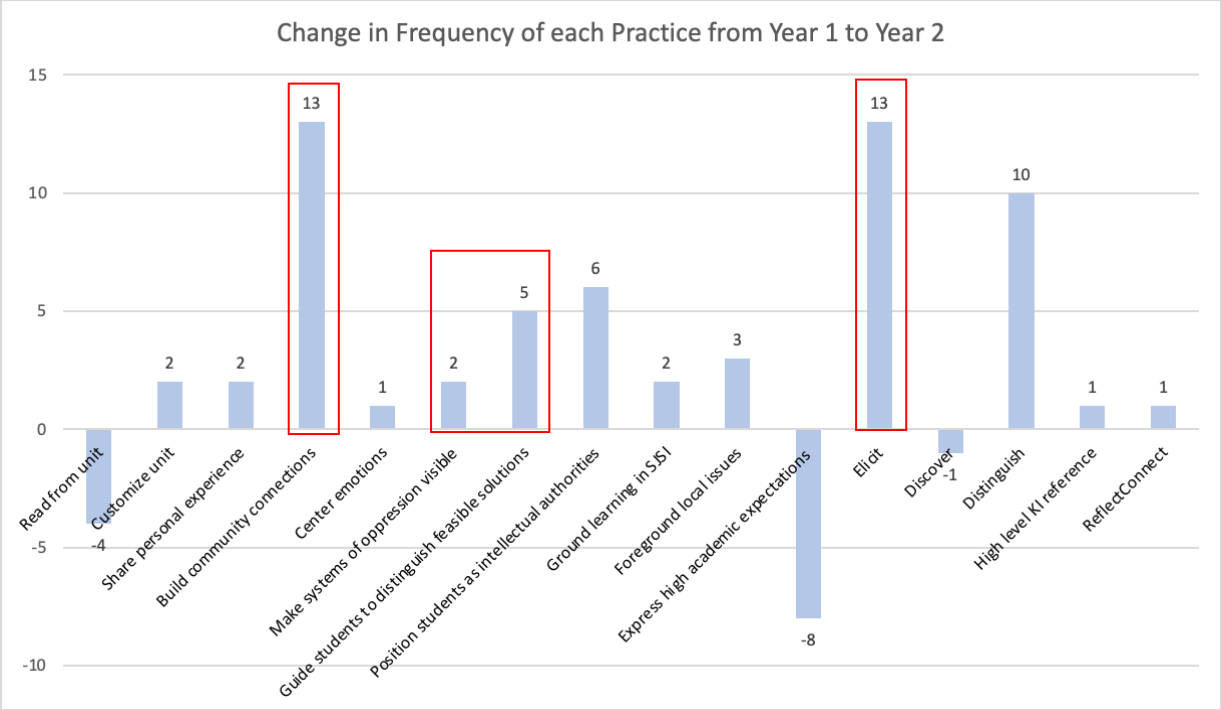


Figure 3.4. Changes in the frequency of each code from Year 1 to Year 2 of the project.

Eliciting Student Ideas and Experiences

Through classroom observations, we observed shifts in each teacher's practice as they enacted the unit for the second time as compared to the first. One trend we observed was that each teacher increased how often they elicited student thinking from Year 1 to Year 2. For Rosie, we noticed that during the first year teaching, she `elicited` student ideas more frequently during the *disciplinary-foregrounded* episode than during the *justice-foregrounded* episode. In Year 2, we observed an increase in her practice of `eliciting` during the *justice-foregrounded* episode leading to comparable frequencies during both episodes. (See Table 3.5). David and Mary shifts

in eliciting were not visible in the episode, but showed up across the entirety of the unit. Looking at the SJSP practices that co-occurred with eliciting, we observed that David emphasized eliciting students' local knowledge and Mary emphasized eliciting their personal experiences. These shifts are discussed in detail in the sections that follow.

Table 5. Summary of the frequency that teachers elicited students' ideas and experiences. Table includes totals for each year, the frequency during the *disciplinary- foregrounded* episode (DFE) and the *justice-foreground* episode (JFE) in each year, and co-occurring SJSP codes.

	Total Y1	Total Y2	DFE Y1	DFE Y2	JFE Y1	JFE Y2	Co-occurring SJSP codes
Rosie	34	43	8	7	3	8	Build community connections (5) Make systems of oppression visible (2) Guide students to distinguish actionable solutions (3) Position students as intellectual authorities (1) Foreground local issues (2) Express high academic expectations (3)
Mary	11	19	0	2	4	3	Share personal experience (2) Make systems of oppression visible (1) Ground learning in SJSI (2)
David	5	12	2	3	2	0	Build community connections (1) Make systems of oppression visible (1) Ground learning in SJSI (1) Foreground local issues (1) Express high academic expectations (1)

Rosie: Eliciting student ideas in Justice-foregrounded episodes

Looking at Rosie's enactment of the unit across the two years we see a pattern emerge when comparing the *justice-foregrounded episodes* and the *disciplinary-foregrounded episodes* (see Table 5). During her first time teaching the unit, Rosie was less likely to elicit student perspectives during the *justice-foregrounded* episode (3 occurrences) than she was to elicit student perspectives during the *disciplinary-foregrounded* episode (8 occurrences). During the *justice-foregrounded* episode, Rosie was more likely to directly share her own understanding with students than to elicit their thinking. However, during the second year of instruction, the frequency at which Rosie elicited students' perspectives and ideas during the *justice-foregrounded* episode rose greatly, going from three instances in Year 1 to eight in Year 2.

The switch to creating more space for student voice may be reflective of Rosie's growing comfort with her ability to respond to and address student ideas, as well as her confidence in the range of ideas that might emerge. During her interview before teaching the unit for a second time,

Rosie expressed that out of nervousness she had over-prepared herself to facilitate discussions in the first year of teaching. She said she spent quite a lot of time learning more about redlining and particularly the redlining practices and lingering effects in their own community around the school: "Well, I definitely went through the [Asthma Unit] very closely. And I, you know, read everything I clicked every extra link, I watched every video, I watched the videos more than once. I did my own searches and read other articles, and I watched other videos on the topic. I watched YouTubes about the history of redlining, so that I would have more background knowledge. Yeah, because I mean, really, I have a science background. I don't have like the political and history background. So… I had to do work to get ready. But then, once I did it, that was more work than I needed to do."

Increased confidence from the first year of teaching, as well as additional knowledge from all her preparation, may have supported Rosie to feel comfortable creating more space for students to voice their thinking. We saw this shift in both whole class discussions and in her individual interactions with student pairs as they worked on their projects. For example, in Year 2, while students were working on activities in the unit with their partners, Rosie overheard two non-Black students arguing about how to interpret the asthma hospitalization data, disaggregated by race. She approached the students and asked them to explain what was going on. One student expressed that he was wondering if the differences in asthma hospitalizations might mean that Black people smoke more than other people, but was worried about writing down the idea because it might be racist. Rosie gently pushed back on the idea by asking the student to consider writing it down as a question instead of a statement. She then probed further, eliciting possible alternatives from the student by saying, "And now, what other explanations might be possible? Let's say we looked at data that showed that [smoking hypothesis] wasn't true. What else could explain it?" Rather than shutting the student down after they voiced a potentially problematic explanation, Rosie asked questions to elicit more of the students' ideas.

Though she had no way of knowing whether the student might double down on deficit-oriented explanations, Rosie opened the space for the student to keep thinking. Fortunately, the student shared that they were also wondering if the disparate asthma hospitalization rates had to do with how close people live to the refinery in their community. Past work has shown that students are likely to abandon new ideas in favor of the initial ideas they have if they don't have the opportunity to distinguish and make connections among them (KI cite). When teaching social justice issues, it is essential to draw out students' ideas so they have the opportunity to put preconceived ideas in conversation with the new ideas and evidence they encounter so that students can develop a deeper understanding of systems of oppression. Having time to explore additional resources and learn about the local history, combined with a second opportunity to teach the unit, provided Rosie with the support she needed to enact strong pedagogy when engaging her students in discussion of race.

David: Eliciting students' ideas about their local context

Similar to Rosie's increased use of `eliciting`, we observed that David engaged students in whole class and small group discussion much more frequently in the second year than in the first year. This resulted in much higher frequencies of KI teaching practices of `elicit`, as well as `discover` and `distinguish`. These differences were more noticeable when comparing Year 1 to Year 2 across the unit generally than in comparing the *justice-foregrounded* and the *disciplinary-foregrounded* episodes.

During the first year teaching the unit, David occasionally `read directly from the unit` materials to provide students with information and launch activities. This occurred on four occasions during his teaching in the first year. However, by Year 2, there were no instances coded where David was reading directly from the unit. This is the only code that showed up with less frequency in Year 2 than in Year 1 for David. Like Rosie, David exhibited more confidence in both his own knowledge of the justice issues in the unit and in his ability to interact with students' ideas about the UHIs and redlining. David's typical pattern of interaction with students in Year 2 frequently looked like posing a question to the class or asking students to make sense of something from the unit, which provided opportunities to reflect on their own prior knowledge. He then would give students time to work in their table groups to exchange and learn from each other's ideas. After some group work time, he held whole class discussions where he elicited perspectives from a range of students and used distinguishing questions to probe students' thinking and prompt them to connect their ideas to evidence.

For example, while the students were at the beginning of the lesson relating UHIs and redlining, David began class by saying "While I'm setting this up, talk in your group about who you think heat waves would affect the most?" He then gave the students a few minutes to discuss their ideas together. He then brought the class together for a discussion, starting by asking, "So what did you do with the heat wave last year? Did you stay inside?" He first elicited students' own experiences with coping with rising temperatures as an entry point to the conversation. He then returned to the question of who would be affected most. When a student shared that how much you are affected would be dependent on where you live, David probed further to prompt the student to elaborate on their reasoning: "What do you mean where you live?" This probe prompted the student to share more and clarify that they meant that it might depend on whether you have the resources you need to mitigate impacts, revealing that they might be thinking about the relationship between socioeconomic status and where someone lives. David pressed further to help the student connect the ideas explicitly, asking, "Oh like if you don't have what you need to stay comfortable through it? Do you mean like city by city or…?" David used these questions to encourage the student to distinguish among their ideas and connect them to begin forming a causal explanation for who is most impacted. In contrast to Year 1, David was able to leverage a variety of KI practices to facilitate his student's sensemaking about a social justice science issue.

Looking at David's classroom, practices `foregrounding local issues` and `grounding learning in a social justice science issue` were also much more frequent in Year 2 than Year 1. While the unit itself framed global climate change as a justice issue, we saw many more instances where David highlighted the justice issues in classroom discussion and `elicited` students' thinking about their local environment during the second year of the teaching.

The code for `foregrounding local issues` showed up about three times as frequently in the second year as it did in the first year of teaching (Appendix A). In David's classroom during the second year, when this practice co-occurred with `eliciting`, it often looked like asking students to think about areas in their neighborhood and use those recollections as evidence to help them make sense of the results they saw using the interactive model or to understand why some neighborhoods within the same city might feel hotter than others.

For example, he `elicited` students' knowledge of the history of their city to make sense of the redlining maps in the unit and to understand why there wasn't data available for the areas that they lived in. While looking at the redlining maps in the UHI unit, David prompted students to consider why there were no color grades in the areas surrounding their school. He said, "I'm

looking for a map similar to this for our area but since this is from the 1930s, how many people do you think lived here then?" He tapped into students' knowledge of the rural history of their city to understand why there might not be redlining maps for their city. He had them make sense of the redlining maps from a city nearby, and told students he would keep looking to find a data source to help explain the systemic forces that influence who is likely to live in a UHI in their community.

During the *disciplinary-foregrounded* episode, David asked students to think about different parts of their city. He `elicited` their knowledge about where parks are located within the city and about areas that had little greenspace. Doing so supported his students to develop a locally grounded understanding of the UHI phenomena and to begin reasoning about who lives in the different parts of their city.

It's possible that David's increase in `eliciting` student ideas about `local issues` stemmed from the time he spent customizing during the summer workshop. He spent time working collaboratively with two other teachers in the partnership who are not featured in this study. During time dedicated to customizing the units, the teachers spent time looking for local datasets. David had reflected that he thought the examples featured in the unit were powerful for his students because they were nearby, but he was hoping he could find something even more local to his students, to places he knew they had been before. While David ultimately did not find any additional data that he wanted to feature in the unit, he spent a lot of time thinking about the effect localizing the unit would have on his students. Spending time doing this may have supported him to seek out opportunities to highlight the local connections to his students while teaching, despite not finding additional data, and ask them to share their experiences as a means for bringing their localized knowledge into the classroom conversation, an important aspect of justice-oriented science teaching.

Mary: Eliciting personal experiences

Eliciting was a key practice in Mary's classroom. In both Year 1 and Year 2, eliciting was the most frequently coded practice in her classroom observations. Like Rosie and David, Mary elicited her students' ideas and experiences more frequently in Year 2 than in Year 1. Another practice that increased for Mary in Year 2 and co-occurred with `eliciting` was encouraging students to `share their personal experiences`. Mary used this strategy to help her students connect to the topics they covered during the unit. For example, during the second year of teaching, while the students were exploring the interactive models in the unit that illustrate how surfaces reflect and absorb different amounts of energy from the sun, Mary asked her students, "How many of you have played sports on natural grass? How many on astroturf? What's the difference in temperature?" With these questions, she invited many of the students in her class who play sports to share their experiences. The class came to the conclusion that astroturf is "crazy hot" and that real plants are more effective at keeping temperatures cool. This conversation sparked more conversation about different parts of the school campus that were warmer or cooler. Marcy asked how many of the students had been in their school's greenhouse before. When most students said they had not, she devised an impromptu "field trip" and walked the class out to the greenhouse so each student could go in and feel the temperature contrast. When they returned to the classroom, they discussed what they had observed and connected their ideas back to their earlier class conversations about the greenhouse effect.

These examples offer an illustration of Mary's aim to support her students to connect the ideas they encountered in the UHI unit with their lived experience. This emphasis on coherence and connection is a key tenet of the KI approach. Mary's instructional choices in the example

reflect her ability to apply a KI approach to ground learning in her students' lived experiences and use those experiences as resources for learning. Doing this more often in the second year might have been in an effort to address a concern she had when reflecting on the first year of teaching. She noted that she believed her students had developed an understanding of what kinds of human activities contribute to global warming and what kinds of surfaces would help reduce temperatures in an UHI, but not an understanding of why: "It was more of a practical application of how can we improve our environment and try to reduce the heating effects, but it didn't really look too much at the other side of that like, like the physics mechanism." It is possible that Mary leveraged student experiences while they were using the models to make sense of the mechanism as a way to help her students develop deeper mechanistic understanding.

Building community connections

Another practice that increased in frequency for each of the participating teachers from Year 1 to Year 2 was `building community connections`. For both David and Mary, the increase was from three instances in the first year to seven in the second. For Rosie, the increase was from 18 to 23. We also observed that `building community connections` co-occurred alongside each of the KI practices. Across the teachers, they leveraged each of the KI practices to accomplish this community building. Both David and Rosie used `eliciting` practices to support community building. David leveraged `discovery` to build classroom community. He often encouraged students to share ideas and learn from each other. Rosie leveraged `distinguishing` and `reflection`. The emphasis on building community across all KI practices indicates how critical it is to develop strong relationships in a classroom in order to engage students in learning about social justice science issues. While Mary did not leverage KI practices in her community building efforts, this was still an important practice for her. In thee second year of teaching, we often observed Mary checking in with students to understand if they were having trouble accessing certain materials or speaking in Spanish to ensure emergent multilingual students were not left out of class discussions. There are many possible reasons for the overall increase in community building. It is possible that the teachers recognized the importance of community after having taught the unit once or that they noticed something about the current group of students to suggest needing to put greater emphasis on community building.

Given the relatively high occurrence of the building community code for Rosie, it is clear that this was a priority for her while teaching the Asthma unit. We focus on her practice of community building to illustrate the importance of community in teaching a justice-centered science unit. During interviews with Rosie, we observed that she had a keen awareness of her students and their relationships with her and with each other. In particular, during the first year of teaching, she believed her students had good relationships with each other, an orientation towards justice and fairness, and supportive families who were eager to have their students address justice issues across their coursework. In reflecting on her first time teaching the unit, she believed those dispositions were critical for supporting them to have conversations about uncomfortable topics in the classroom. With this in mind, Rosie foresaw different challenges with teaching the unit in the second year of the project. She reflected that the relationships among the students looked different than they did in the prior year. In particular, she noted that students were much more prone to make light of and joke about racial issues. She noted that the concern persisted even after having conversations with students individually and the seventh grade class as a whole having conversations with teacher leaders and administrators to address the harms being caused by making

such jokes. With this in mind, Rosie shared that she was particularly attuned to how she paired students when they were working on that project.

This focus was reflected in the teaching practices she enacted while teaching the unit. Looking at Rosie's facilitation in the *Justice-foregrounded episode*, the `building community` and `centering emotions` codes were much higher in frequency during the second year than in the first. This shift might be due, in part, to her specific attention to supporting students to engage compassionately in the discussion of sensitive content that they have been known to joke about in recent weeks in the school year. Rosie's teaching moves to `build community` often looked like framing comments about how students should work together and treat each others' ideas. `Centering emotion` is a related, but slightly different practice that is closely linked to Rosie's community building efforts. For Rosie, this looked like expressing her own feelings about the topic they were learning and suggesting and validating a range of feelings students might be having. For example, when examining the Asthma hospitalization data that had been disaggregated by race, Rosie pointed to the bar for African Americans on the graph and said, "This bar, this should make us angry. If this makes you feel uncomfortable, you're in good company." She validated that the data could evoke an emotional response and signaled that she also had strong feelings in response to what she saw. In the same lesson, she also acknowledged that students might feel uncomfortable talking about race when interpreting the data. She said, "I want to acknowledge that this might make you a little uncomfortable, we tend to shy away from talking about race stuff. But the data is really clear so we don't have to shy away from it. It is clear that Black and African American people have a much higher rate [of asthma hospitalization]." Acknowledging students' discomfort while encouraging them not to look away from the data is an important part of fostering students' ability to discuss injustices.

Fostering critical consciousness by making systems of oppression visible and guiding students to distinguish actionable solutions

Two SJSP practices that frequently co-occurred with KI practices were: `making systems of oppression visible` and `guiding students to distinguish actionable solutions` (See Table 3.6). Both of these practices are means of fostering critical consciousness. One interesting pattern that emerged when looking across codes was that `making systems of oppression visible` co-occurred alongside each of the KI processes. Further, each of the three partner teachers exhibited at least two instances of engaging teaching moves to `make systems of oppression visible`. This suggests that teachers are finding multiple avenues to support their students to develop critical consciousness.

Table 3.6. Frequency that teachers engaged practices to foster critical consciousness in Year 1 and Year 2 and the co-occurring KI practices.

Teacher	Total Year 1	Total Year 2	Co-occurring KI practices
Make systems of oppression visible			
Rosie	10	8	Elicit (2), Discover (1), Distinguish (2), Connect (1)
Mary	6	6	Elicit (1), Discover (1), Distinguish (2), Connect (2)
David	0	5	Elicit (1), Discover (1)
Guide students to distinguish actionable solutions			
Rosie	10	7	Elicit (3), Distinguish (9)
Mary	6	13	
David	2	3	

All three teachers provided students with opportunities to `discover` new ideas as a means of `making systems of oppression visible` on at least one occasion across the two years of teaching. While this is not very frequent, these were examples of instances where the teachers moved beyond the opportunities that were designed within the unit for students to explore evidence and uncover the relationships between health outcomes and systemic racism. Rosie and David both leveraged primary source redlining documents to help students uncover evidence that racist beliefs, rather than economic policies, motivated redlining policies. Doing so gave students an opportunity to understand how systemic racism has influenced housing policies, leading to racially disparate health outcomes.

Mary: many approaches to foster critical consciousness

Mary leveraged a variety of KI practices to `make systems of oppression visible` and had a variety of approaches to `guide students to distinguish actionable solutions`. One approach Mary took was to support students to `discover` new ideas that illuminated systemic racism by engaging with ideas held by their peers. During a class discussion about who is likely to live in UHIs and the consequences of living there, Mary lifted up an idea that had been raised by a student in another class period. She shared, "something one of the other classes said that I thought was interesting is that people need to go outside in the evening to stay cool." Mary elevated this student's idea which brought forth a new perspective for the students in the observed class period to consider. The discussion that followed supported students to consider the safety consequences of needing to be outside to cool down in neighborhoods that are predominantly people of color and that are likely to be more heavily policed. The discussion helped

students interrogate connections between living in an UHI and an increased exposure to possible police violence. Students' critical consciousness was cultivated as they examined how systems of oppression can intersect to produce negative outcomes for marginalized peoples.

In Mary's practice, she also often drew on the KI processes of distinguishing and connecting as pedagogical tools to structure the ways she fostered critical consciousness. For example, when having a discussion with students about which communities are most impacted by the urban heat island effect, we saw Mary use distinguishing questions in order to press for her students to be clear when speaking about racially disparate impacts. An instance of this occurred when Mary was holding a discussion with her students about the health impacts of UHIs towards the end of teaching the unit. She asked students, "Who is mostly impacted by the UHI effect?" A student responded by saying "low income neighborhoods and people of color." Mary prompted students to distinguish by pressing the students for clarity by saying, "We keep saying people of color. *Who* are we talking about?" She continued to ask questions until students were able to express that the evidence they explored indicated Black and Hispanic Americans were experiencing the greatest share of health issues related to UHIs. By pressing students to be specific, Mary encouraged them to name directly who is experiencing the greatest harm from systemic racism and not shy away from speaking directly about the systems of oppression shaping outcomes in our society.

We also saw her leverage the process of connecting as a means to `make systems of oppression visible`. She used connecting questions during class discussions to help students link evidence of racially disparate health outcomes that they had gathered across the different units they had learned about in her science class, such as a unit about the Covid-19 pandemic. She used this approach to guide students to build a clear picture of how systemic racism and systems of oppression operate to create disparate outcomes. She leveraged public health as a central concept to connect evidence from topics like inequitable distribution of vaccines during Covid-10, unequal access to health care, and increased likelihood of suffering health consequences from living in high temperatures. Her objective was to help students build the case that across many health phenomena there is evidence that Latinx and Black people are more impacted. She emphasized to students that these are not just coincidences, but rather paint a picture of how our society is structured to disproportionately harm people of color. Quote here. Further, she leveraged this as an opportunity to support students to think about the way that science can be used as a tool to make systems of oppression visible and understand how they are operating across multiple domains of society.

Mary also fostered students' critical consciousness by customizing a final project for the UHI unit that engaged students in `distinguishing actionable solutions`. She designed a project where students worked with partners to draw their city on a long piece of paper. She had them draw the same city block twice: once illustrating the city as it currently is, and on the other side drawing in potential solutions to reduce the impact of the urban heat island effect in those areas. On one side of their drawings, Mary had students describe and list the health effects associated with living in an urban heat island, the policies that shaped who is most likely to live in and be impacted by urban heat islands, and definitions of redlining. On the other side of the poster students were asked to list potential paths forward to minimize the existence of urban heat islands, including mechanistic descriptions of why the solutions they proposed would reduce the temperatures in the areas that they were created. Mary particularly favored this solution because it required students to work together and exchange ideas. She also appreciated that by drawing the same city block twice, students would recognize some of the limitations in designing solutions, such as the constraint that you cannot move people out of their homes or knock down buildings

where people work and live to make parks with grass and trees. This constraint supported students to think realistically about solutions they could advocate for.

Looking across Year 1 and Year 2, we observed other ways that Mary guided her students to distinguish actionable solutions as a means of positioning them as transformative intellectuals, a part of fostering their critical consciousness. This was something that Mary did during the first year of teaching the unit, particularly in the *Justice-foregrounded episode*. In the second year of teaching, we saw that Mary positioned students as transformative intellectuals throughout the entirety of the lesson, not just in the *Justice-foregrounded episode* and final project. For example, she situated the UHI unit into a broader unit on climate change and sustainability. To do so, she interleaved activities about sustainability practices, like water conservation, throughout the entire unit. She guided students to think about climate change mitigation strategies as well as adaptations to cope with a changing climate. Throughout the unit, she engaged students in using their science knowledge to envision practical actions toward furthering their sustainability practices at home and emphasized actually making changes in their own lives or with their families. During a conversation about increased occurrence of droughts and the importance of water conservation, for example, she talked to students about possible water conservation practices and asked them which they would be willing to try. When many of her students expressed an interest in taking shorter showers, Mary got shower timers from their local water district to distribute to students so that they could actually take stock of their attempts to reduce their water usage at home.

She supported students to think about the impact of conserving water beyond the global impact of saving water, but also to think about how it would impact their families as resources become more expensive. She encouraged them to share their ideas with adults at home to see if they could impact their water bill. She also spent a lot of time discussing the personal impact of making changes. For example, she asked students how it felt to take shorter showers and whether it felt like they still got clean. She asked students about other water conservation practices they were trying and whether it seemed like too much of a hassle to make those changes, foregrounding the necessity of engaging solutions with actions one can sustain. She encouraged students to share: "Okay, how many of you tried your water saving things? How many of you used the shower timer? How many felt it was hard? How many of you felt like you got out just as clean? A little less clean? I want you to keep track of that." She placed an emphasis on supporting students to make choices that they could sustain. She encouraged them to adopt practices that could become part of a lifestyle switch, as opposed to something that they found so inconvenient that they would abandon it.

While this approach to positioning students as transformative intellectuals by `guiding students to distinguish actionable solutions` is more focused on taking action at the individual level, rather than at the systems level as advocated for in Morales-Doyle's (2017) example, Mary still encouraged students to use their science knowledge to think about how they could improve conditions for themselves and for their families. Further, Mary expressed that it was important for her students to begin seeing in small ways how they can use science to inform their decision making. During her interview prior to teaching the unit, Mary shared that part of her goal was to help students "use science to make better decisions to protect people because [across history] everybody gets moved to the cities and everybody's exploited." She wanted the UHI unit and broader unit on sustainability to serve as a starting point for her students to make informed decisions and resist exploitation.

Rosie: positioning students as transformative intellectuals

Like Mary, Rosie also foregrounded `guiding students to distinguish actionable solutions` as a means of fostering critical consciousness and positioning students as transformative intellectuals. While this practice often co-occurred with `eliciting` in Mary's classroom, it was more likely to co-occur with `distinguishing` in Rosie's classroom. For Rosie, one priority was to support students to deepen their engagement in the "Call to Action Project" in the second year of teaching. In reflecting on the first year teaching the Asthma unit, Rosie noted that many of her students focused their final projects on individual actions to mitigate climate change, like walking to school. This led Rosie to wonder whether her students had an understanding of the kinds of actions they could take to address more complex issues like the lingering effects of redlining or air pollution from freeways, factories, and refineries.

In response, Rosie planned a class discussion during the second year of teaching to give space for students to develop understanding of the actions available. She used the discussion to help students surface big picture solutions and think through the corresponding action steps. This served to make the issues and potential solutions more tangible and actionable to students. For example, during the discussion, some students suggested that factories and refineries should not be in neighborhoods where people live. Rosie followed up by asking students, "So, if you think we should make it so the factories aren't by people, what are you going to have them do with the existing ones?" Students responded by saying the factories should be shut down and then relocated to areas where people don't live. Rosie pressed further by asking, "So if that's your solution, what steps do you do to make that happen?" This led to a conversation about the potential for collective action and how to leverage protest and other means to get your government to take action in service of your community. Rosie used distinguishing questions to support students to think through the feasibility of solutions and identify actual action steps to bring about the solution. Helping students identify action steps is critical for empowering them to be transformative intellectuals who feel capable of enacting change.

David: Discussion and summative project to foster critical consciousness

While the unit was designed to raise student understanding about systems of oppression and how they operate to produce inequitable outcomes, we did not see any instances where David explicitly supported students' thinking about such systems during the first year of teaching. During the first year he did engage students in thinking about redlining, largely drawing on the unit as a resource to read from before having students work through the unit with their table groups. He also made a few moves to support students to think about how they could take action to mitigate contributions to climate change and envision solutions to the UHI phenomena.

In year two, however, there were five occasions where David leveraged class discussions to explicitly attend to the development of students' critical consciousness. In class discussions, he posed questions to students to get them to consider who is most likely to live in an UHI and what kinds of information was used to develop redlining maps. For example, he asked students "Which areas do you think got marked as best?" when they were looking at how areas near them were graded on redlining maps. He opened space for them to develop an understanding that these policies were rooted in racist beliefs and have contributed to systemic racism. These discussions supported students to move beyond thinking about this issue as being whether or not one can afford living in a neighborhood with greenspace to interrogating how systemic racism has shaped access to such neighborhoods.

The increased attention to making systems of oppression visible and movement towards positioning students as transformative intellectuals also showed up in the ways that David

customized the final project for the unit. In the first year, David decided to use the final project that has historically been associated with the WISE Global Climate Change unit. This project guided students to create a personal climate action plan where they made suggestions about how they and their family could take steps to mitigate their contribution to climate change. In the second year, David opted to use the final project that Mary had designed. By adopting this project, David's students needed to connect their understanding of climate change and UHIs to redlining and racially disparate health outcomes. This provided students with another opportunity to express their understanding of how systemic racism influences outcomes in our society and to consider actions they can take to bring about more just outcomes.

Summary

These shifts in practices illustrate an example of how starting from quality, co-designed materials designed to engage students in learning about social justice science issues can serve as a strong starting point while teachers develop their comfort in and ability to engage their students in learning about such issues. Further, it is possible that having the opportunity to interact with other teachers and learn about their approaches to facilitating discussions alongside the unit supported him to leverage these KI practices.

Fostering critical consciousness and positioning students as transformative intellectuals are broad and ongoing goals of justice-oriented science teaching. There are many approaches to supporting students to develop critical consciousness and many aspects of critical consciousness that can be developed through science education. The examples from the teachers in this study illustrate a variety of entry points for fostering critical consciousness in the science classroom.

We found that there were a number of KI and SJSP codes that frequently overlapped, suggesting that those utterances and the surrounding classroom activity are where we can see how these two pedagogical approaches fit together to support students integrating an understanding of typical disciplinary knowledge with understanding of systems of oppression and social justice issues that are local to their communities. Examining these co-occurrences provides a concrete, grounded perspective on what it might look like to integrate social justice and knowledge integration pedagogy for our teachers who have been developing their KI-aligned science teaching practices for years but are newer to integrating social justice content in their classrooms and to adopting justice centered pedagogy. These overlaps indicate high leverage starting points where teachers can build on their existing pedagogy and extend into achieving their aims for justice centered science teaching.

Discussion and Conclusions

This study presented the case study of three experienced science teachers adapting their curriculum and teaching practices to integrate social justice into their science teaching. The partner teachers each taught a unit that featured a local social justice science issue (SJSI) and participated in RPP activities focused on customizing the units, examining student work, reflecting on effective practices, and sharing ideas with other teachers. Each teacher taught their unit twice, once during each year of the project. We found that teachers cultivated their KI and SJSP teaching practices over the two years, demonstrating shifts in their teaching approach from Year 1 to Year 1. Examining student learning gains across the two years of the project, we found that students, on average, made greater pre to posttest gains in the second year as compared to the first, suggesting the impact of the refined units and approaches used by the teachers in Year 2. Looking across the

cases, we see multiple entry points for teachers to develop their practice for integrating social justice into their science classrooms. The development across two years of implementation suggests that teachers are better able to bring their practices into alignment with their perspectives and goals.

Leveraging Existing Pedagogy for Justice Centered Science Teaching

Drawing on the KI (Linn & Eylon, 2011) and SJSP (Morales-Doyle, 2017) framework, the RPP envisioned justice-oriented science teaching that looked like science teachers eliciting and valuing ideas from all students; supporting students to discover evidence in the context of local justice issues; pressing students distinguish among their ideas to explain causes of racially disparate health outcomes; and guiding students to reflect on ways to bring about a more just world. By examining the intersections of KI practices and SJSP practices, we were able to better understand how our partner teachers leveraged their existing KI-informed pedagogy in combination with SJSP practices.

For example, looking across our teachers, we found that the KI practice of eliciting co-occurred with all but one SJSP practice. This signals the importance of teachers making space to learn from and about their students' ideas, experiences, and beliefs during all aspects of a unit featuring local SJSI. This is aligned with other work that suggests that teachers are most successful at enacting culturally responsive practices when they identify science topics that are relevant to their students' lives and taking an asset-oriented view on students (Brown & Crippen, 2017). In order to fully understand what topics will be relevant to students and to identify SJSI that are meaningful to students, teachers must first elicit and respect students' ideas and experiences as important for shaping the learning in the classroom. By emphasizing the practice of eliciting students' ideas and experiences and using those ideas to drive the learning, teachers communicate an asset-oriented view of their students.

Eliciting student ideas in the context of social justice science issues can be daunting for teachers as they are less familiar with the kinds of ideas students have about such topics and there is the potential for students to express ideas that are disrespectful or harmful. We observed that the partner teachers, Rosie and David in particular, became more likely to elicit their students' ideas when discussing justice issues in their second year of teaching. These teachers already demonstrated skill in eliciting student ideas in typical discussion of disciplinary topics. They were able to apply this pedagogical approach more consistently and during the discussion of sensitive justices issues in the second year of teaching. This suggests that as teachers become more confident in their own knowledge of the topic and more familiar with the range of ideas their students are likely to express, they are more likely to create space to elicit student thinking.

Another key practice that emerged in this work was building classroom communities. This is not surprising as most educators would agree that strong classroom relationships are essential to support learning. Further, Brown & Crippen (2017) also identified building community as an important lever for teachers to enact culturally responsive practices. The partner teacher used a variety of KI practices to support community development in their classrooms, suggesting that there are multiple approaches that teachers can employ to foster community. David's approach emphasized supporting students to learn from a build on each other's ideas as a means to build community. Rosie emphasized eliciting ideas from all students, providing scaffolds to support students to work together and productively ask each other distinguishing questions when they disagree, and centering the emotional component of learning about social justice issues. For Mary, many of her community building approaches involved speaking to students in their home

languages and encouraging them to do so with each other as well and expressing care and concern when students did not turn in assignments. These approaches are more localized to the classroom community than in the example shared by Morales-Doyle (2017). The learning activities of the chemistry unit he describes also extend connections from the classroom to students' home communities by including family members and leveraging the expertise of local community members (Morales-Doyle, 2017). It seems that building community within the classroom is a first step toward fostering the trust and norms of engagement that might enable broader community connection.

Over the course of the project, teachers developed approaches to leverage KI practices to foster critical consciousness and to position their students as transformative intellectuals. Fostering critical consciousness is a key component of teaching social justice in science (Morales-Doyle, 2017; Madkins & McKinney de Royston, 2019). Like building community, these are broad goals for justice-centered science education that can be approached in many ways. The approaches leveraged by Rosie, David, and Mary illustrate a wide range of priorities and corresponding approaches for student development in terms of their critical consciousness and ability to take action for more just outcomes.

Value of RPP Focused on Customization for Local Issues

Participating in the RPP activities over the course of the project might have supported the shifts in practice and perspective we observed from the teachers. Prior research has demonstrated the power of engaging in curriculum customization for teacher learning and curriculum improvement (Ball & Cohen, 1996; Gerard, et al., 2011; Remillard, 2000; Goldman, Hmelo-Silver, & Kyza, 2022). While engaging in the RPP activities, like curriculum customization, analysis of student work, and sharing effective practices with other teachers, our partner teachers had opportunities for professional learning. One activity that might have been particularly impactful was the positioning activity where teachers reflected on how their own histories and identities intersected with the histories of their students and of the social justice issue featured in the unit they teach (Gerard et al, 2022). After engaging in this activity, we observed that two of the teachers expressed deeper personal connections when describing their perspective on why social justice should be taught in science. One of these teachers shifted from viewing the purpose as solely to increase the relevance of the content to expressing a perspective that justice issues are inherently linked to the disciplinary topic he was teaching, climate change. It is possible that engaging in RPP activities supported these shifts.

Further, through the experience of customizing the units to be better suited for their own students and to align to their local context, the teachers had an opportunity to learn more about the justice issues themselves. Two of the partner teachers were more willing to engage their students in discussions about the justice issue in the second year of teaching. It is possible that the added confidence of teaching a unit for the second time, combined with the knowledge gained during the customization process, supported teachers to create more space for student ideas and feel more comfortable having spontaneous discussions with students about sensitive topics.

Future Work

While the present study provided insight into the shifts in perspective and practice exhibited by the teachers over the course of the project, we can only hypothesize about the experiences and activities that supported the shifts we observed in the teachers. Future studies could focus on systematically studying the impact of certain RPP activities on teacher practice. As

more science teachers seek to incorporate social justice into their science teaching, it is critical to understand the mechanisms that support teachers to incorporate justice-oriented pedagogies into their existing practice.

Chapter 4: Developing an AES Model for Student Explanations of Social Justice Science Issues

Introduction

This study reports on the development of an automatic scoring model that assesses students' ability to explain Social Justice Science Issues (SJSI; Morales-Doyle, 2017), issues that can only be explained by integrating understanding of science topics and of social justice. Research has long suggested the importance of connecting science learning to real-world contexts and, more recently, to issues of social justice (Buxton, 2010; Barton & Tan, 2010; Dimick, 2012; Morales-Doyle, 2017) for engaging all students in developing deep understanding of science. We argue that for students to develop robust, integrated understanding of many scientific phenomena, such as climate change or the occurrence of health issues, teachers must attend to social justice by centering culture, race, and identity in their instruction. While many teachers are eager to do so, this requires expertise and knowledge that goes beyond typical science instruction (Brown & Crippen, 2017; Madkins & McKinney de Royston, 2019). Teaching SJSI can create challenges for teachers as they invite social justice ideas and new perspectives into their classrooms.

Teachers need to develop new practices to support students to express their social justice ideas and connect them to their disciplinary ideas to develop integrated understanding. In general, science teachers need to be able to recognize and respond to their students' ideas (Robertson et. al., 2015) in order to effectively support students' development of their understanding. In the context of social justice-centered science education, teachers need to adapt to recognizing ideas and perspectives they have not previously encountered in their classrooms, and they might need support to better access their students' thinking.

As teachers engage in work to advance their understanding of social justice issues, they can be supported by curriculum materials that structure opportunities for students to express their thinking about social justice issues in science. Further, tools taking advantage of advances in Artificial Intelligence (AI) have been put forward to support teachers' abilities to access the range of ideas held by their students (Gerard et al., 2020; Bichler et al., 2021) and might be useful tools for helping teachers understand how their students are making sense of social justice issues. However, as AI capabilities advance and are increasingly applied in educational contexts, we must consider how best to leverage these tools to support students to develop integrated understanding of science phenomena and social justice issues.

In service of developing AI tools that support social justice-centered science learning, our research practice partnership (RPP) leveraged the Knowledge Integration Framework (KI; Linn & Eylon, 2011) and natural language processing (NLP) approaches to develop automated essay scoring (AES) models to automatically score student explanations of SJSI (Morales-Doyle, 2017). We explored whether we can develop AI tools that provide insight into student learning about social justice science issues. We aimed to measure the degree to which students explain a science phenomenon, the intersecting justice issues, and how well they connect ideas from those domains to demonstrate integrated understanding. We designed score reports within a suite of teacher tools that accompany the units and support teachers to access their students' ideas and provide feedback.

This study builds on findings from the first study presented in this dissertation (Bradford et al., 2021) that suggest the importance of providing teachers with access to their students' ideas both during instruction and again while making customization decisions between rounds of implementation. It also builds on findings from other studies conducted with the RPP (Bradford & Gerard, 2022; Bradford et al., 2023) that suggest that teachers need additional support to assess

whether and how their students are connecting their understandings of the typical disciplinary topics with their understanding of the justice issues presented in the units. In this study we ask:

- Can we develop NLP models that accurately capture students' integrated understanding of SJSIs, both in terms of human-computer agreement and the teachers' perspectives?
    - Which model NLP produces best overall agreement with human raters?
    - How do teachers make sense of and use NLP-generated scores for students' explanations of SJSIs?
- How do teachers' instructional decisions after reviewing the NLP-generated score report impact student explanations of SJSI?

Theoretical Perspective

This study has been informed by prior research in several areas: integrating social justice into science curriculum; supporting teachers to notice and respond to their student ideas; and leveraging AI techniques to score student essays and convey information to teachers. I briefly review these bodies of literature in the sections that follow.

Social Justice Science Issues (SJSI)

As discussed in depth in Chapter 3, there have been increased efforts to illuminate the necessity of centering issues of social justice in science teaching and learning. One productive avenue towards achieving social justice science curriculum is to ground traditional science teaching in local social justice science issues (SJSI). Many have argued that students can learn state required disciplinary content through learning tasks that engage students in political struggle and address issues of injustice in their local communities (e.g., Barton & Tan, 2010; Barton & Tan, 2020; Buxton, 2010; Corburn, 2005; Dimick, 2012; Morales-Doyle, 2017). Morales-Doyle (2017) clarifies that social justice science issues go beyond the exploration of local, socioscientific or "real-world" issues because they "cannot be understood or addressed apart from understanding and addressing oppression." (p. 1036). Addressing such issues necessitates that both students and teachers learn about the historical and political intersections with standards-aligned science content.

Introducing SJSIs provides opportunities for students to make sense of issues impacting their own communities and raises issues around inequality and racism (Morales-Doyle, Childress Price, & Chappell, 2019). In making sense of such issues, students might leverage typical science ideas to interpret how an environmental phenomenon impacts people and integrate those ideas with social justice ideas to help them determine why the impacts are different across racial and socioeconomic groups. Developing such science units can involve a lengthy design and iterative refinement process because it requires attention to existing curriculum standards and demands nuanced depictions of social justice issues (Kraig-Turner, 2016; Marks-Block, 2011). For example, Morales-Doyle (2017) reports on a chemistry unit that supported students to succeed academically and learn standards-aligned content while also identifying instances of environmental racism and seeking ways to enact positive change for their community.

In this study, we combined social justice science pedagogy (Morales-Doyle, 2017) with Knowledge Integration (KI) design principles (Linn & Eylon, 2011) to design units featuring SJSI and an assessment item, the *Impacts* item, that captures the degree to which students integrate their understanding of standards-aligned disciplinary concepts with their understanding of local SJSI. Further discussion of how these frameworks come together to inform curriculum design and teaching practice can be found in Chapter 3. Taken together, these frameworks also inform the

design of models used for scoring student explanations on the *Impacts* item and the teacher report that displays information and scores for teachers. Our aim was to develop models that can accurately measure learning that is aligned to this pedagogical approach and develop teacher reports that use scores from the models to further teachers' abilities to engage in justice centered knowledge integration.

Supporting Responsive Teaching of Social Justice Science Issues

As discussed in the previous chapter, developing teachers' understanding of social justice issues and the intersecting history and policies that have been enacted in their local communities is essential for supporting teachers to integrate social justice in their science teaching. In addition to developing teachers' content knowledge, teachers need support to adopt social justice-centered teaching practices and to consider how to leverage their strong science pedagogy in the context of teaching SJSI. Prior work within the RPP has illustrated that many of our teachers have strong pedagogical approaches to support their students to develop coherent explanations of scientific phenomena, but those approaches do not necessarily translate to other contexts (Bradford & Gerard, 2022). This suggests a need to support teachers to build pedagogical content knowledge (e.g., Magnusson, Krajcik, & Borko, 1999; Shulman, 1986) at the intersections of science and social justice. Further partner teachers have expressed the challenge of determining the degree to which their students are developing understanding of the social justice ideas and connecting them to their science understanding (Bradford et al., 2023).

This study seeks to explore how to enhance teachers' ability to access their students' ideas and consider an appropriate pedagogical response to respond to the ideas their students hold. We build on the success of the teacher report, the Teacher Action Planner, described in Study 1.

AI in Education

At the same time as there has been increased attention to shifting science education to include interrogation of social justice science issues and the harms wrought in service of scientific advancement, there has been an explosion of interest in leveraging artificial intelligence in education (AI; Baidoo-Anu & Owusu Ansah, 2023). In this study, we particularly focus on using AI to automatically score student explanations of SJSI and generate reports to help teachers better access the ideas in their student explanations. In the sections that follow we provide a brief overview of some of the ways AI has been used in education and explore the literature on automated essay scoring (AES) and tools that provide information to teachers.

AI is not new to the education space: it has been used to expedite automated scoring in high stakes assessments (e.g. Attali & Burstein, 2006), provide automated feedback and guidance to students on products of their learning like short essays (Gerard & Linn, 2022; Gerard et al. 2022; Putambekar, 2023) or scientific models (Zhai et al., 2022), and provide teachers with learning analytics tools, like dashboards, to support them in responsive teaching (Dickler, Gobert, & Sao Pedro, 2021; Gerard & Linn, 2016; Gerard et al. 2020; Tissenbaum & Slotta, 2019; Van Leeuwen & Rummel, 2022; Vitale et al., 2016). AI has also been used to individualize student learning experiences in intelligent tutoring systems (Doignon & Falmagne, 2012; Heffernan & Heffernan, 2014; Koedinger et al., 1997; Pardos et al., 2023) and educational chatbots that provide direct guidance or hints to students as they engage in learning tasks in many domains (e.g. Bradford et al., 2023, Pérez-Marin, 2021; Subramaniam, 2019). The impact of chatbots on learning outcomes is not yet clear (Wollny et al., 2021). A recent study comparing the impact on learning gains of hints generated by ChatGPT and hints generated by human tutors found that both sets of hints

produced positive learning gains, though only the gains from human tutor-authored hints were statistically significant (Pardos & Bhandari, 2023).

In this study, we focus particularly on the development of automatic essay scoring (AES) models that capture students' level of understanding of typical disciplinary concepts, understanding of social justice ideas, and their integration of the two. We leverage these scoring models to create a learning analytics display that supports teachers to access their students' ideas and levels of understanding. In the sections that follow, we review the seminal literature in the fields of AES and AI-powered tools that provide feedback to teachers that have enabled the work in this study.

Automated Essay Scoring (AES)

The field of automated essay scoring (AES) can be traced back to Page's (1966) early work on to Project Essay Grader (PEG) system which leveraged computers to grade essays and found that a computer rater's score was nearly as highly correlated with human raters' scores as the human raters' scores were with each other. Since this time, there have been many advances in the field and AES models are widely used in classrooms and high stakes assessments, for example the e-rater automated scoring system (Burstein, 2003) that used for the GMAT. In this paper, we are particularly interested in methods for short answer scoring, a slightly different task from AES in that AES is often concerned with scoring writing quality while short answer scoring is often concerned with content scoring (Burrows et al., 2015). In short answer scoring, the goal is to develop an AES model that can assess the quality of a short, student-generated free-text response according to a scoring rubric. Early work in the short answer scoring includes c-rater (Leacock & Chodorow, 2003). C-rater works by determining whether a natural language response is part of the set of correct ideas that could be expressed in response to the prompt. To do so, the model uses a number of natural language processing techniques to normalize a response by attending to sources of variation in expression of the same idea: syntactic variation, morphological variation, pronoun reference, the use of synonyms or similar words, and spelling or grammatical errors.

Recently, researchers working on short answer scoring have sought to incorporate approaches that have been effective in the realm of AES (e.g. Riordan et al, 2017) like the use of neural architectures (e.g. Zhao et al., 2017) like pre-trained transformer models (e.g. Yang et al., 2020). In particular, we build on the work of Riordan et al. (2020) that found that recurrent neural network and pre-trained transformer models performed just as well or better than feature-based models and that the pre-trained transformer-based models were more robust to spurious, dataset-specific learning cues, better reflecting scoring rubrics. We adopt a similar approach leverage pre-trained transformer models to develop short answer scoring models for KI, *disciplinary*, and *justice* scores.

Teacher Feedback Tools

We also build on work focused on leveraging AI techniques to provide information and feedback on teaching to teachers with the aim of supporting them to be more responsive to their students. There are a variety of approaches to providing this information to teachers, including learning analytics dashboards and providing automated feedback to teachers.

Many tools that automatically provide feedback to teachers focus on student engagement and progress, cueing teachers when they need to intervene to keep a student on track (e.g. Alrajhi et al., 2021; Aslan et al., 2019). While helpful, these tools do not necessarily provide teachers direct feedback on their teaching practices. Recent work has developed approaches to better center

feedback for teachers. For example, Demzky et al. (2023) put forward M-Powering Teachers, a tool that leverages natural language processing to give teachers automated feedback on their uptake of student contributions. Uptake refers to building on a students' contribution through acknowledgement, repetition, and elaboration (Collins, 1983; Clark & Schaefer, 1989). Teachers' uptake of student contributions is a key aspect of responsive teaching. The M-Powering Teachers tool is an entirely automated process whereby teachers' lessons are recorded, anonymized and transcribed, and then the transcripts are analyzed using an automated metric for uptake (Demzky et al., 2021). Based on the analysis of teachers' uptake, teachers were given nonjudgmental, concise, and actionable feedback at regular intervals. They found that teachers uptake increased by 13% in response to the feedback, suggesting the promise of their approach.

Another approach to leverage AI to provide teachers with information to support their teaching practice has been learning analytics dashboards that display instructionally relevant data about their students' learning process or outcomes. The goal is to provide teachers with just-in-time information to inform pedagogical decision making. Across the field, dashboards range in function. Some alert teachers to students whose engagement or progress indicate a need for intervention, others provide access to information about students' scores or ideas. Some support the interpretation of information about student learning and others recommend teacher actions or interventions. Some alerting dashboards are designed to direct teacher attention to students based on progress through a learning task (e.g. Tissenbaum & Slotta, 2019) or student performance based on automated scoring (e.g. Dickler, Gobert, & Sao Pedro, 2021). Dickler, Gobert, & Sao Pedro (2021) found that students' scientific inquiry improved after teachers intervened based on alerts from their dashboard, Inq-Blotter. Other dashboards are designed to be accessed by the teacher as needed during instruction or to plan for the next class period (e.g Aleven et al., 2016; Gerard et al., 2020; Wiley, Diamitriadis, & Linn, 2023). The Teacher Action Planner (TAP) (Gerard et al., 2020; Wiley, Diamitriadis, & Linn, 2023) provides teachers with information about students' performance along multiple dimensions of the next generation science standards (NGSS) based on scores of students' written explanations. The TAP also provides teachers with key insights and recommended actions to help teachers interpret the score patterns and plan pedagogical action. Findings suggest that some teachers take up the recommended actions, while others plan alternative interventions or rely on already planned activities to support further learning for students (Gerard et al., 2020).

Given the potential of learning analytics-based dashboards to provide teachers with greater access to their students' thinking (Gerard et al., 2020, Bradford et al. 2021) and to support them to take action (Wiley, Diamitriadis, & Linn, 2023), this study focuses on the development of AES models that are leveraged to produce a dashboard for teachers. Specifically, in this study, we explore how to leverage AES models to provide analytics that support teachers to responsively adapt their instruction based on their students' ideas, building on previous work with the TAP. Echeverria et al. (2018) argue that to make a learning analytics dashboard actionable for teachers, not only does the dashboard need to be aligned to a theory-grounded learning design but it also needs to present data directly related to what designers and teachers identify as the educational objectives. As such, the dashboard in this study is designed using the KI framework and perspective on learning (Linn & Eylon, 2011). Further, the data displayed are from an item that is aligned with the teachers' objective of integrating social justice into science.

Methods

This study employs a design-based research (DBR; Schoenfeld, 2006) approach. We use mixed methods including observation, interview, and quantitative analyses (t tests, correlations, quadratic weighted kappa) to evaluate the NLP scoring model and how embedding the resulting scores in score report within the teacher tools impacts teacher practice and student learning.

Conjectures

Based on the literature reviewed above, this study is guided by the following design conjectures:

- We can develop an AES model that can accurately (as compared to human scoring) measure integration of science and social justice ideas.
- We can use pre-trained transformer models and instance-based approaches to develop one model that can be accurately deployed in two units.
- A KI-informed teacher dashboard featuring student responses, autoscores from NLP models, key insights, and recommended actions will support teachers to make instructional decisions and reflect to plan for next year.

By engaging teachers to support the design of the NLP models and the teacher dashboard, we also seek to explore what teachers find useful for assessing SJSI. By embedding the teacher dashboard into teacher classrooms, we seek to better understand how teachers interpret and respond to the scores generated by the NLP models and other insights captured in the dashboard.

Model Development

We developed an AES model to automatically score an item, *Impacts*, that is found in two units: Global Climate Change and Urban Heat Islands (UHI; 9th grade) and Chemical Reactions and Asthma (Asthma; 7th grade). The item asks students to explain whether all people are impacted by climate change in the same way. The item is on the pre/posttest and is embedded within the unit at the end of the lesson focused on the social justice science issue. In the Asthma context, the item prompt elicits ideas about combustion reactions and asthma. In the UHI unit, the item prompt elicits ideas about the urban heat islands phenomenon. In both contexts, students connect their science understanding to the role of race, socioeconomic status, and policies like redlining in their local communities.

Scoring Rubrics

To develop the scoring model for the Impacts item, we first developed a knowledge integration (KI) rubric (scale 1-5; Liu et al., 2016) and two subscore rubrics (scale 1-3). The rubrics are shared in Table 4.1. One subscore, *disciplinary score*, characterizes how students integrate climate science ideas in their explanations and is aligned with the next generation science standard (NGSS) performance expectation associated with the unit. The second subscore, *justice score*, characterizes how students integrate ideas about historical policies and social injustices into their explanations. The KI rubric measures the integration across these two domains. We developed rubrics for the item in both the Asthma and UHI unit contexts. All rubrics reward students for linking their ideas and connecting evidence and do not penalize students for incorrect ideas.

Training Dataset

We applied the rubrics to data from previous classroom studies where students responded to the *Impacts* item, approximately 1600 responses from the Asthma unit and 600 responses from the UHI unit. The student responses are short essays, typically ranging from 1-3 sentences long. The

students represented in the training data are from schools that have similar demographic distributions to the schools in the present study. To assess reliability before building the models, two raters independently applied the rubrics to 5% of the data and then calculated Pearson's kappa to measure our interrater reliability. We discussed disagreements and refined the rubrics. We repeated the process until we achieved a kappa > 0.85 for the KI, Disciplinary, and Justice scores. The remaining data was split 50-50 among the two raters and hand scored.

Table 4.1. Rubric for KI and disciplinary and justice subscores.

Prompt
Do you think all people are impacted by the effects of climate change in the same way? Explain.

Target Ideas:
Disciplinary Ideas

- Climate phenomena [UHI]: Examples of regionally specific impacts of climate change, cities/concrete/roads/urbans areas heat up faster than rural areas/areas with greenspace, concrete etc. absorbs more solar radiation that transforms into heat energy
- Proximity and access to green space [UHI]
- Depends on proximity to a source of pollution/low air quality [Asthma]
- Exposure to heat [UHI] and air pollution [Asthma] impact human health

Justice Ideas [Both units]

- Current/historic policies have a role (redlining, or other policy)
- Social factors like race, ethnicity or SES have a role in how much someone is impacted

Disciplinary and Justice Subscore: 0 – Target ideas not present; 1 - Vague or full description of one target idea; 2 – Linked two or more target ideas

KI score	Criteria	Example response
1	No answer; irrelevant	idk
2	On topic, nonnormative; normative but vague (without explanation)	Yes, climate change will effect everyone in the whole world.
3	Partial link: one target idea	Yes, because if you have more freeways or factories where you live you could have more of the effects of incomplete combustion than places without many. If you live near refineries and places with fewer trees you will also be impacted more, though everyone is impacted to some extent..
4	Full link: links two target ideas	I think that people who are lower income are impacted by climate change more than people who aren't. I think this because they sometimes have to live closer to factories and other places where there could be harm.
5	Full links: links three or more target ideas	NO! Racially oppresed groups are affect more by climate change. These groups are in redlined communities which put near industrial areas which produce green house gases. These greenhouse gas emmisions give you a higher chance to have asthma.

Model Development

These human-scored data were used to train models for KI, Disciplinary, and Justice scores. Models were developed using pre-trained transformer models (see Riordan et al., 2020 for details of the approach). Models for each score type were trained independently, each score representing the quality for an aspect of the content of the response. The models are trained for content scoring and ignore spelling, grammar, or usage errors. The models are trained to predict an ordinal score (1-5 for KI, 1-3 for *justice* and *disciplinary*) based on the text in each response. We used an "instance-based" model (e.g. Horbach & Zesch, 2019) where the model did not have access to expert-authored model responses or data augmentation. This instance-based enables the model to learn the lexical properties of responses at each score level and can score responses of any length without additional modeling complexity. While instance-based models do not tend to generalize well across prompts (Horbach & Zesch, 2019), we anticipated that responses generated by UHI and Asthma versions of the *Impacts* item would not cause an issue. Many ideas or phrases associated with high level scores are the same in both unit contexts. Ideas that are specific to a particular unit context are unlikely to occur in the other context, minimizing the likelihood that an n-gram associated with a high score from one unit context would be associated with a low score in the other unit context.

We used pre-trained transformer models in the development of our scoring models. The standard instance of the BERT model (Devlin et al., 2019) was used for the KI and *disciplinary* scores. BERT is a bidirectional transformer model trained on the tasks of masked token prediction and next sentence prediction across very large corpora (Books Corpus and English Wikipedia). For the *justice* score we use SciBERT (Beltagy, Lo & Cohan, 2019), a model based on BERT and trained on a corpus of scientific publications across from multiple domains. During training, a special token '[CLS]'is added to the beginning of each input sequence. To make predictions, the learned representation for this token is processed by an additional layer with nonlinear activation, outputting a score prediction. The model was 'fine-tuned' by training the additional layer's weights on the dataset.

To validate the effectiveness of our models, we employed various statistical measures, including quadratic weighted kappa to assess the agreement between the model's scoring and human raters, ensuring reliability. To assess validity, we will also examine the correlations among the scores, anticipating the KI will be closely related to both *disciplinary* and *justice* scores since KI measures the integration of these scores. We anticipate that *disciplinary* and *justice* will not be highly correlated as students can use ideas from either domain to justify their explanation and the domains are distinct.

Our approach to address equity concerns with using AES in classrooms

We recognize that there are a range of concerns with using applications of AI tools, like AES, in a classroom setting (e.g. Li, et. al., 2023). We have taken several measures to address these concerns. First, we were intentional about what type of learning task we selected to develop an AES model and teacher-facing score report. We used an item that is a low-stakes assessment that is situated midway through a unit and on the posttest, after students have had ample opportunity to explore their own ideas, the ideas of their classmates, and ideas generated by activities in the units. Further, the design and placement of the item, as well as our approach to scoring it, were informed by two pedagogical frameworks to ensure we are assessing the kind of learning that matters for our objectives, rather than letting technological capabilities drive our development. To that end, we leveraged the KI Framework (Linn & Eylon, 2011) to develop an

AES model to automatically score student explanations of SJSI (Morales-Doyle, 2017). Taken together, these frameworks require an open-ended phenomenon-based question that can only be explained by connecting a wide array of ideas and interrogating the systems of oppression that contribute to the phenomenon. Our approach to scoring the item emphasizes the connections students make among their ideas and does not penalize students for expressing non-normative ideas. Additionally, we ensured that we were able to collect training data from student populations that matched the students who would be learning from the units and having their explanations scored by the model.

Teacher Action Planner (TAP)

To support teachers to access their students' ideas and make sense of patterns in the degree to which students are developing understanding in the *justice* and *disciplinary* domains as well as how well students are connecting across, we leveraged a dashboard called the Teacher Action Planner (TAP; Figure 4.1). The TAP is designed from the perspective of KI pedagogy, emphasizing the way students are connecting ideas. Teachers were given a TAP display after their students completed the embedded Impacts item. Teachers received a Revision TAP after their students completed the Impacts item on the posttest. Both the TAP and Revision TAP, feature histograms displaying students' automatically generated KI, *justice* and *disciplinary* scores. The Revision TAP displays both the embedded and posttest scores. The lighter bars indicate scores on the embedded instance of the item and darker bars indicate posttest scores. Below each histogram, there is a description of what each score level means. There is also a section for "Key Insights" which supports teachers' interpretations of the histograms.

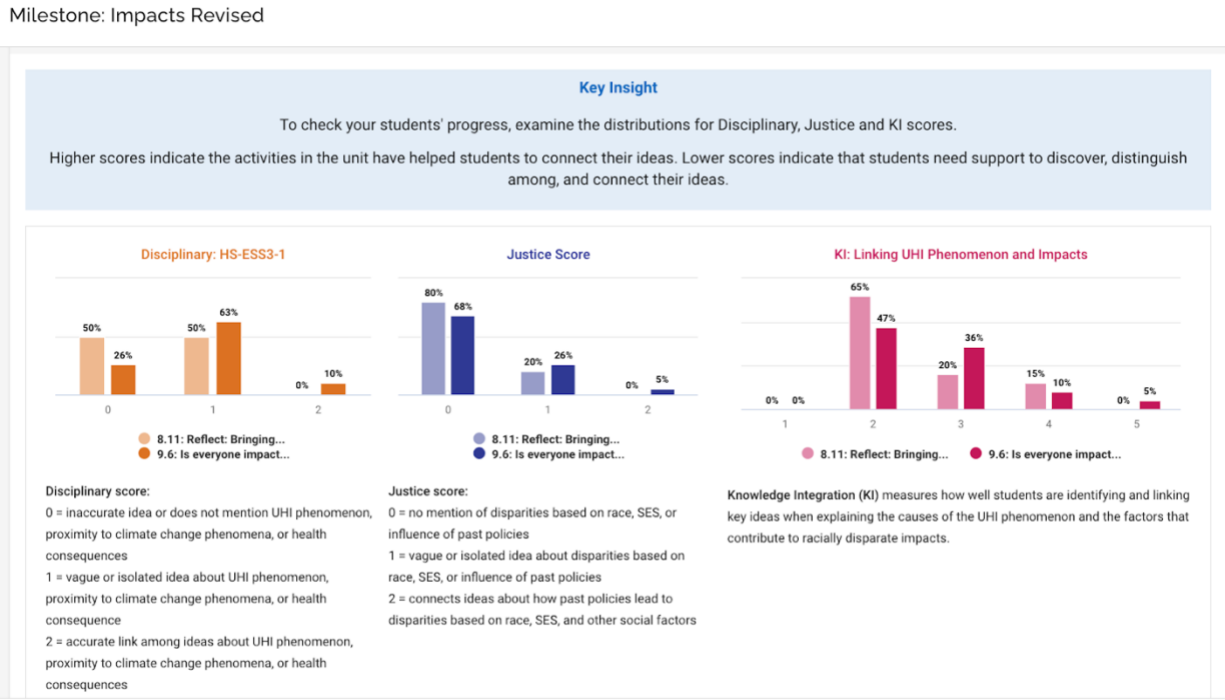


Figure 4.1. The Revision TAP key insights, score histograms, and score level descriptions.

Below the histograms, there is a section with Recommended Actions for an activity the teacher could complete to support their students to build from their ideas to form more coherent explanations (Figure 4.2). The activity is structured using the KI framework and displayed to

teachers with actions for each KI process. Past research on the design of the TAP has found this to be an effective way to suggest actions to teachers (Wiley, et. al., 2023). Additionally, teachers are able to toggle between the Recommended Actions and individual student work. The Student Work view displays each students' explanation and the KI score for that explanation in a table (Figure 4.3). On the revision TAP, teachers see the students' embedded and posttest explanations, columns with the scores for each of those explanations, and a column that captures the change in score from bedded explanation to revised posttest explanations. Teachers can sort student work using the score columns and change in score columns.

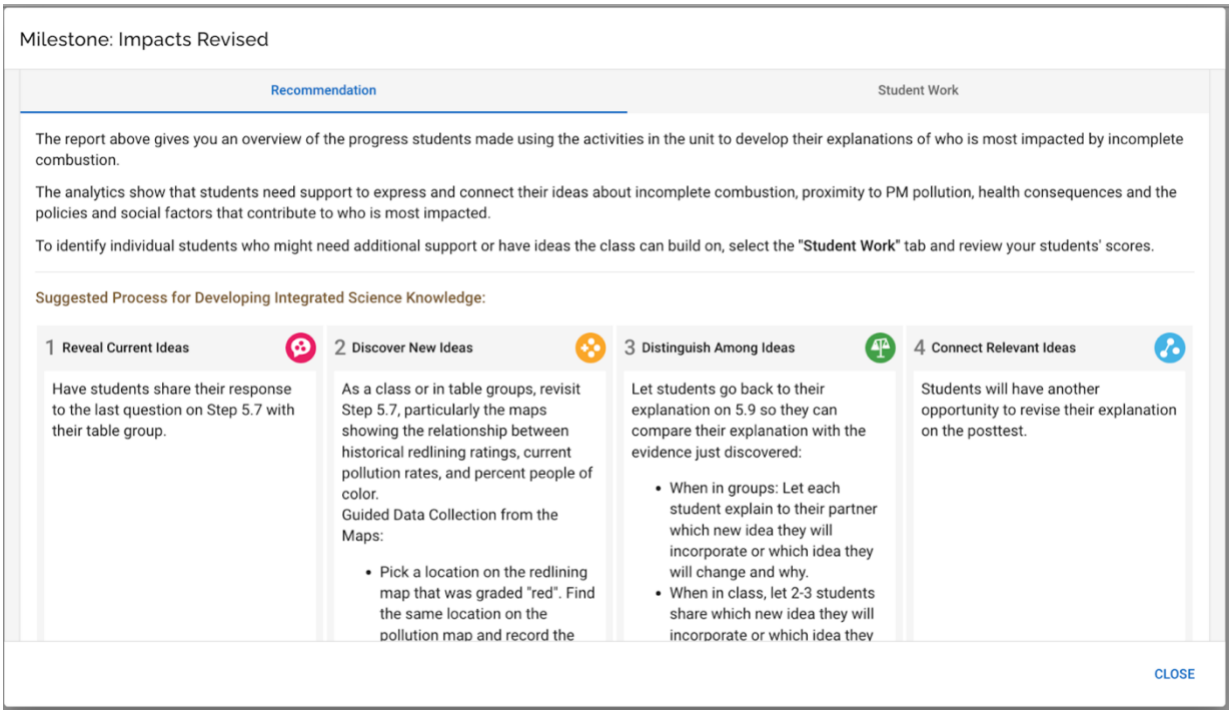


Figure 4.2. Recommended Actions view in the TAP.

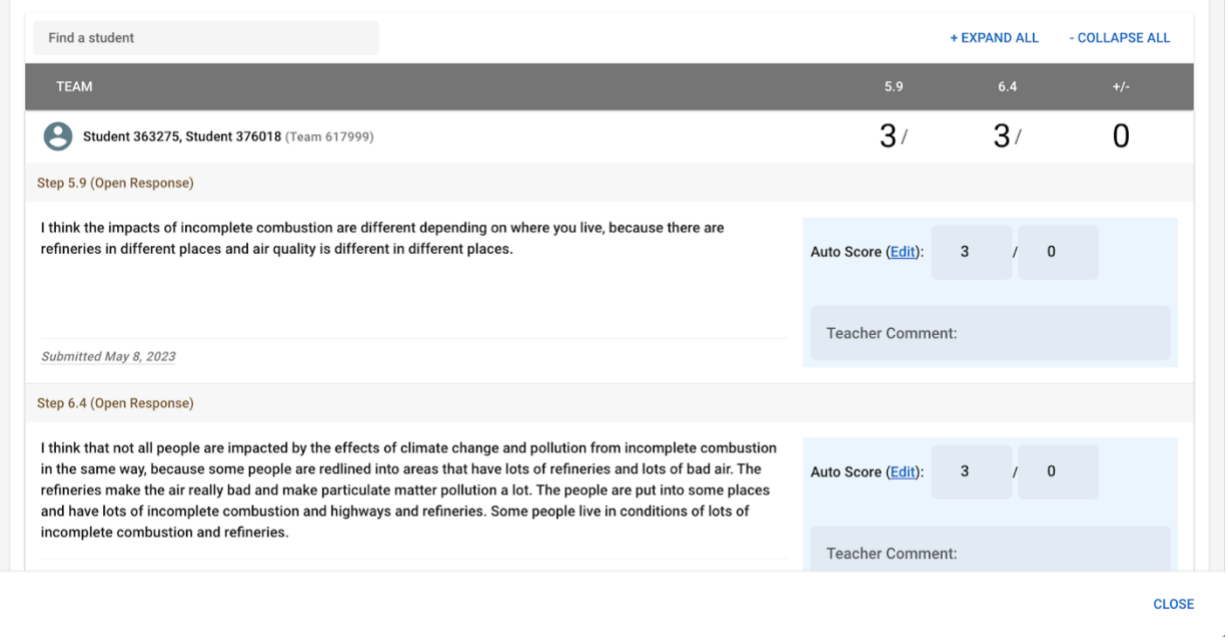


Figure 4.3. Student work view in the Revision TAP.

Partner Participants

The participants in this study are part of a larger partnership composed of middle and high school science teachers, learning scientists, curriculum developers, and social justice experts. The partnership is focused on integrating social justice into science curriculum and leveraging AI tools to support equitable learning in the science classroom. This study focuses on three partner teachers and their students: David, a high school biology teacher who identifies as White; Mary, a high school biology teacher who identifies as Hispanic; and Rosie, a 7th grade science teacher who identifies as White. All teachers teach at racially, ethnically, and linguistically diverse schools. All three teachers have participated in the RPP for at least five years. During those years, they have taught units that feature a variety of AI tools: NLP scoring models that provide automated feedback to students based on their scores, NLP-driven chatbots that detect and ask questions about students' ideas, and teacher dashboards displaying summaries of scores aligned to dimensions of Next Generation Science Standards (NGSS). They have focused on integrating social justice into their science curriculum for the past two years.

Classroom Testing

We embedded the *Impacts* item with scoring models at three time points in the units: on the pretest, within the unit at the end of the lesson about the justice issues, and on the posttest. The KI score, disciplinary score, and justice score for student explanations from the *Impacts* item were provided to teachers through a suite of teacher tools, displaying class-level histograms of each score alongside scored individual student responses (Figure 1). Mary and David taught the UHI unit (student N= 95) and Rosie taught Asthma (student N = 56). We interviewed the teachers about integrating social justice and science and about their approaches to assessment, including using score reports and the other teacher tools, before and after they taught the unit. We also observed at least one class period for each teacher every day throughout the duration of the unit. We use a case study design to characterize each teacher's approach and student learning. We describe the perspectives teacher's shared on the tool during interviews, their reactions when viewing the tools

and score report while teaching, and any action they took upon reviewing the report. We use paired t tests to evaluate changes in students' KI, disciplinary, and justice scores at each time point.

Results

We first present results from our AES model development and evaluation process. Next, we share the three participating teachers' perspectives on and use of the teacher tools, including the reports displaying the scores generated by the NLP model. Finally, we examine students' learning by evaluating the changes in student scores on the *Impacts* item from pretest to posttest.

Model development

Our goal was to determine whether we could develop models that could accurately capture students' disciplinary and social justice ideas in both units, despite the units featuring different SJSI. Using 10-fold cross-validation and an 80-10-10 training-validation-test split, we developed models using only data from the Asthma unit, only data from the UHI unit, and combined data from both units. We then tested each model on students' responses from both the Asthma and the UHI units. Using quadratic weighted kappa as a metric, we found the combined model performed best for *KI, disciplinary,* and *justice* scores for data from each unit (Table 4.2). The only exception to this trend is the *justice* score in the UHI context. The model trained only on data from the Asthma unit performed better at determining the justice score for data from the UHI context than either the model trained only on UHI data or the combined dataset. This might be explained, in part, by the fact that there were fewer responses in the UHI dataset overall, leading to a smaller representation of the ideas that are assessed by the *justice* score. Interestingly, the model trained on data from both units yielded a higher QWK (see Table 2) for the *disciplinary* score when evaluated on data from each of the unit contexts as compared to model trained and evaluated on data from the same unit. This is surprising as the ideas assessed by the disciplinary score are more different across unit contexts than the ideas in the justice score. It is possible this result is due to having more data in the combined dataset.

Table 4.2. Model evaluation results (quadratic weighted kappa, QWK) for models trained on data from the Asthma context, the UHI context, and a merged dataset.

Training Context	Evaluation Context	KI QWK	Justice QWK	Disciplinary QWK
Asthma	UHI	0.7349	0.7810	0.6475
Asthma	Asthma	0.8657	0.8257	0.9028
UHI	UHI	0.7678	0.6647	0.7207
Combined	Asthma	0.8680	0.8281	0.9062
Combined	UHI	0.7943	0.6712	0.8020

To examine the validity of the constructs behind each score, we examined the correlations among the KI, disciplinary, and justice scores using the training data. As we expected, we found a high correlation between KI score and disciplinary score ($r=0.77$, $p<0.001$). We also found a moderate correlation between KI score and justice score ($r=0.48$, $p<0.001$). We found low

correlation between disciplinary score and justice score ($r=0.15$, $p<0.001$), suggesting that these scores are measuring distinct constructs.

Teacher Cases

To better understand the value of the scoring model, we created a teacher report that displays class-level histograms of the *KI, disciplinary,* and *justice* scores, as well as individual student responses, key insights and recommended actions. We interviewed and observed the three partner teachers to understand the value of the scoring model and corresponding reports. In the sections that follow, we share case studies to describe the teachers' perspectives on and use of the teacher report.

David

Prior to teaching the unit, David expressed excitement about having the teacher report for the *Impacts* item. He was particularly enthused that it connected a NGSS high school performance expectation to justice ideas. He believed the score report linked to the performance expectation would be valuable for justifying his use of the social justice-centered curriculum to his administration. He also believed this emphasized that students wouldn't fully learn about climate change if they did not also examine the justice implications. The approach enabled him to "broach the subjects as one package that you can't just separate."

While teaching the unit, David continuously monitored student progress using the teacher tools. He used them to keep track of which students had completed which activities and to look at individual student responses to questions. He used that information to give instructions to the whole class and decide when to bring the class together for activities. For example, while students were working in their table groups, David decided to give his students more time to keep working before coming back together as a class. He said, "I can see that about 2/3 of you are done with WISE. I can see your progress and everything you write." He used the tools to keep track of student progress and also reminded his students that he was keeping track of their work.

When reviewing the embedded TAP during teaching, David noticed that there were differences in *justice* and *disciplinary* scores between class periods. He was not surprised by this and attributed it to the interests within the class. He shared that his second period was performing better on the justice score than some of his other periods. He interpreted this by leveraging his knowledge of his students: this class period had more students driven towards social justice causes than in his other periods. David also reflected that students were not as familiar with redlining as he had hoped. While teaching in the previous year, he had many students taking a sociology course that taught students about redlining. He hoped to have a similar number of students in that course and elevate their expertise to support their classmates' learning. Looking at the justice scores in the TAP highlighted that he did not have that expertise in the classroom. He also noted again how useful the report was: "[The TAP] show[s] admin how useful the curriculum is even though questions are asked in a research kind of way." He believed the reports would help illustrate the value of having research-based curriculum in his classroom.

In response to what he observed in the report, rather than designing a new activity or using one from the recommended actions, David planned a discussion to go between the embedded item and the posttest to help students discuss the justice issues as they connect to Urban Heat Islands. David began the next class period by sharing with students what he has seen in the teacher report:

> "It's an opportunity to make connections. Individual concepts we're knocking out of the park. We need to make more connections. How does that science concept connect to redlining. You can tell me the order of things, but I want you to connect. These are things I think you know but I need to know that you know. If you can focus on making connections, that's my advice for you. I get a lot of teacher data and I can really know what you know as a class."

David used what he had seen in the reports to emphasize to his students that it was important for them to be thorough in their responses by including all their ideas and discussing the connections between them. This reminder to students reflects a KI perspective on learning by emphasizing the connections among disciplinary and social justice ideas – a goal that the TAP sought to emphasize.

After teaching, when asked how well he thought the unit helped students develop an understanding of urban heat islands and who is most impacted by them, David used the dashboard to answer this question without being prompted to look at it. After pulling up the report, he shared, "On the high school standard, the KI score went up to more fours and fives had a huge change from two to three… but kind of marrying that to the social justice score I would have liked to see that same increase". He leveraged his understanding of the KI framework to make sense of the numerical scores and reflect on his students' learning. He also reflected that he wished the unit fell earlier in the school calendar so that he had more time to respond to what he'd see in the TAP:

> "We just have like all these lingering questions at the end, and then we have to move on to the next thing. And that's just kind of the way we have so much packed into our freshman bio class. It's just a bummer… they like started to make those connections, but like, there's definitely lingering questions and the milestone reports [TAP] help trying to confirm where they're at…I wasn't really able to make it land if it didn't land for the first attempt. So trying to reteach that, I didn't have that luxury."

David reflected that the TAP did not reflect the progress he had hoped to see on his students' *justice* scores but he didn't have time left in the school year to adjust his teaching plan to support students to deepen their understanding of the justice issues and make stronger connections. He hopes to devote more time to build connections.

Mary

Before teaching the unit, Mary expressed excitement about having automated scores for a question about the SJSI. Mary had used previous versions of the TAP when teaching different units that did not feature SJSI. She was eager to explore its use in this context. She shared that she finds the TAP beneficial: "I can use it in my warm-up to make sure I'm, you know, going over that [areas with low scores] a bit more to clarify." Her past experiences with the TAP made her eager to use one for the *Impacts* item.

While teaching the unit, Mary consistently had teacher tools open and expressed eagerness for her students to get to the prompts with TAPs. During each class period, she used the teacher tools to check students' work from the previous day. She asked students to revisit parts of the unit if they had not completed all the activities in that portion or had given insufficiently detailed responses. She looked at students' written responses to get a general picture for the depth at which

students were responding to prompts and made announcements to the class to clarify how she wanted them to approach the problems. For example, midway through the unit, after students had answered another autoscored item, she said to the class, "When folks are typing in your responses, I'm noticing that you aren't include a lot of details. I'm getting a note that says you need to connect more evidence in your answers. So really try to think about the details and make sure you're answering the question being asked." She used the tools to gauge students' understanding and to remind students of her expectations that they write detailed responses that connect their ideas to evidence from the unit.

Towards the end of the class period where more of her students had reached the *Impacts* item embedded after the lesson about the justice issues and some had completed the posttest, Mary reviewed the TAP. She taught on a block schedule, which resulted in many students answering both the embedded and posttest instances of the *Impacts* item during the same class period. Looking at the TAP, Mary was very disappointed in both embedded and revision scores: "Man they really chunked it on this question". Looking at the histograms, Mary observed that students were scoring mostly 2s on the KI score and 1s on the justice and disciplinary scores, suggesting that students were not yet expressing explanatory ideas. Because Mary knew the scores were generated using a newly developed scoring model, she asked me to human check model scores to confirm whether her students had expressed more elaborated understanding than indicated by the model scores. She was not confident that these scores accurately reflected her students' level of understanding. After looking at the scores, Mary expressed that she thought her students' explanations indicated that they needed more opportunities to discover and connect ideas about redlining and UHIs. The next day, she did a whole warm-up to engage students in making connections across the unit topics. She started class with the following questions on the board: "1) How is electricity associated with greenhouse gasses? 2)What is redlining? 3)Are the environmental impacts of human activities equally felt/experienced among all members of a population? Explain. 4)How can plants help to reduce the heat island effect?" After giving students time to work on the warm-up individually, Mary conducted a whole class discussion to review the questions. She commented to students that, "we've been looking over your answers in the WISE project, and there's no explanations of why." She pressed students to explain why when they orally shared answers during the discussion. Mary commented after class that students orally expressed more of the ideas she was hoping for than she saw in their written responses.

After completing the unit, when asked to reflect on how well the unit supported her students to connect their ideas about UHIs to ideas about social justice, Mary said, "I mean they were terrible at first and they got better right yeah so I thought that was good. There was a big move from basically having everybody… what is this last one? Linking the phenomenon to the impact… at the start it was like 65% were two and then by the next go around only 40%. A bunch of them moved to Level 3 so that was good and somebody made five." Similarly to David, Mary drew on her experience and knowledge of the KI pedagogy to interpret the scores that were displayed in the dashboard as well as in individual student explanations. In reflection on why her students had lower justice scores than disciplinary scores she recalled that during class discussions, one student got really uncomfortable talking about racism. She voiced, "I think it was interesting that one kid didn't want to say racism when we were doing the warm-up… he was uncomfortable… that was something I think that came up this year that I don't seem to recall last year." She agreed this might contribute to lower justice scores because if students were uncomfortable discussing the impact of historically racist housing policies, they are likely uncomfortable writing about it too.

Further, after using the TAP to review a number of individual students' responses, Mary noticed that many of her students only focused on one way in which climate change might not impact all people in the same way. For example, some students would only explain that climate change is different for different people because different areas experience different kinds of extreme weather, while others would only focus on access to greenspace or policies like redlining. When thinking about teaching the unit again, Mary suggested that students might benefit from some additional scaffolding activities to help draw out all their ideas and then have an opportunity to reflect on how they connect prior to responding to the *Impacts* item. She suggested that students could start with a check all that apply type question: "You can have like geographical location. You can say race you could say SDS, right you could say like several different things. And then maybe choose all that you believe apply and for each give a brief explanation." Mary suggested this activity be followed by a question that prompted students to reflect on whether they'd thought about how these different categories were linked together and to explain the connections they see. Mary believes that including these activities next year will support her students to make more connections and write more elaborated explanations.

Rosie

Prior to teaching the unit, Rosie expressed mild interest in the TAP and agreed to look at it when her classes reached the *Impacts* item. Her primary comments were less about the TAP itself and more about the *Impacts* item that was embedded in the social justice lesson. She noted that "particularly this year that they [her students] have a lot of, like, fatigue, like answer fatigue. So, like, I get worse and worse answers as time goes on, even though they're learning more and more." With this challenge in mind, she suggested ways to encourage students to bring their full effort to the *Impacts* item: "I'm just wondering if the question were somehow like, called out as like, okay, we've learned a lot of stuff. Now, here's the most important question or it's yellow or like the, the big idea question, just some way that it's called out as, like, more than the rest, and that they should actually pay attention to [it]". In response to this feedback, we changed the format of the presentation of the *Impacts* item in the WISE unit.

Overall, when her students completed the embedded instance of the *Impacts* item, Rosie was disappointed in the scores she saw in the TAP. She had hoped to see higher *justice* scores. She relied heavily on the research interpretation of the scores and seemed uncertain about whether the scores reflected her students' level of understanding or if it reflected the level of effort they put into writing their responses. Rosie was already planning to have a whole class discussion to review the social justice-centered lesson and she hoped that the discussion would help her get a clearer picture of the levels of understanding her students had.

During the whole class discussion, Rosie projected activities from the WISE Asthma unit to review asthma data, PM pollution maps, redlining maps, and to support student understanding of redlining policies. The discussion typically followed the format of Rosie displaying an activity from the unit and then asking students to share their thinking about it. She often called on multiple students to share for each question and would often follow up on a students' response by asking them to explain their thinking. The class discussion lasted for the majority of the class period. Students returned to the WISE unit and completed the posttest after the discussion. When reviewing the TAP after the posttest, Rosie indicated she was still disappointed in the scores displayed. She shared concerns about whether the prompt was sufficient for eliciting the target ideas and that she was generally disappointed in the effort students put forth into all assessments

this year. She noted that "students aren't writing anything wrong they just aren't elaborating." This led to Rosie feeling frustrated that she couldn't be certain about students' level of understanding.

Students also completed PSA Poster projects as a final summative assessment for the unit. In the projects, students had to select a key topic from the unit and create a poster that would raise awareness and call for action in their school community. In our interview a few weeks after she taught the unit, she reflected that she couldn't tell from her students' written responses to the *Impacts* item or their final project whether they had really engaged in the sensemaking she'd hoped for. She expressed that she couldn't tell whether her students were regurgitating what she wanted to hear or had really internalized ideas about the connections between the causes and impacts of particulate matter pollution and the policies and power structures that contribute to the racially disparate rates of asthma. She expressed that she needed to hear students discussing their ideas to better gauge how much they understand.

Rosie also offered feedback on the design of the TAP to suggest how it might have been more useful for her in assessing her students and making sense of their levels of understanding. One area she thought could be improved is the section that provides insight into what each score means. She shared that "If you see those lower scores, then I just feel like oh, well, that wasn't good. I don't really know why or what to do about it." She went on to explain that she needed more in the TAP report itself to help her understand what kinds of ideas are present in a high scoring response and what is missing in a low scoring response. Rosie also expressed that she was able to understand the report a little better while teaching the unit because I was there to talk it through with her: "Well, because I think when you were showing it to me, you said things that made sense that were helpful, but I didn't notice those on the page. I think if you hadn't been talking me through it, I would have just maybe been like a little mystified like what exactly does this mean? What's missing?" The TAP on its own did not provide Rosie with what she needs to understand and take action based on her students' scores and responses. She wanted the report to contain more specific information about what ideas were encompassed within each score level, without providing too much text or example that the TAP would be overwhelming to look at. As Rosie put it, "If I know exactly what it is that you were looking for, then I would have a better solution." For the TAP to be actionable for Rosie, she needed a deeper understanding of what each score level means and the ideas that are typical for students to express at each score level.

Like Mary, Rosie also thought that her students might benefit from a more specific prompt that cues the range of ideas she is hoping for them to express in response to the *Impacts* item. She is eager to try out a different version of the report and prompt in the next school year.

Looking Across the Teacher Cases

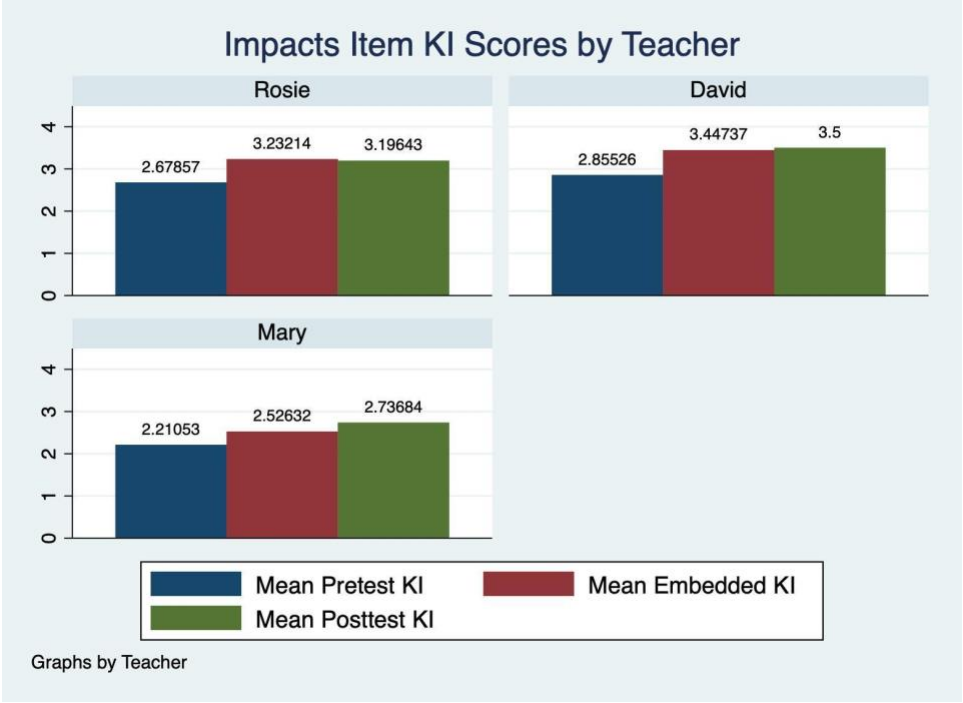
Each of the teachers used the TAP to reflect on their plan for the next class period. One teacher used the tool to validate the choice she had made about leading a whole class discussion the next day. She hoped the discussion would both improve her students' understanding and help her gain a better sense of what her students are thinking about. Another teacher used the TAP as a signal to remind students about the kinds of connections he was looking for in their written responses. The third teacher used the TAP to plan a warm-up that would help her see if students had ideas they weren't writing down. Across all three, the TAP seemed to prompt a wondering as to whether students were expressing the full range of their understanding in their written responses to the *Impacts* item. Two of the teachers opted to use activities where students needed to discuss their ideas to supplement their understanding of student thinking gained from the TAP. All teachers used the TAP as more of a reflective tool to gauge the effectiveness of their teaching and

plan for teaching the unit again in the future. Teachers attended to differences in disciplinary and justice scores during instruction. One noted that the students started with vague ideas about the SJSI but shared more detailed ideas orally. Another reflected that the progress on the science topic was greater than the progress on the SJSI. The teachers used the score reports to reflect on improvements to the unit.

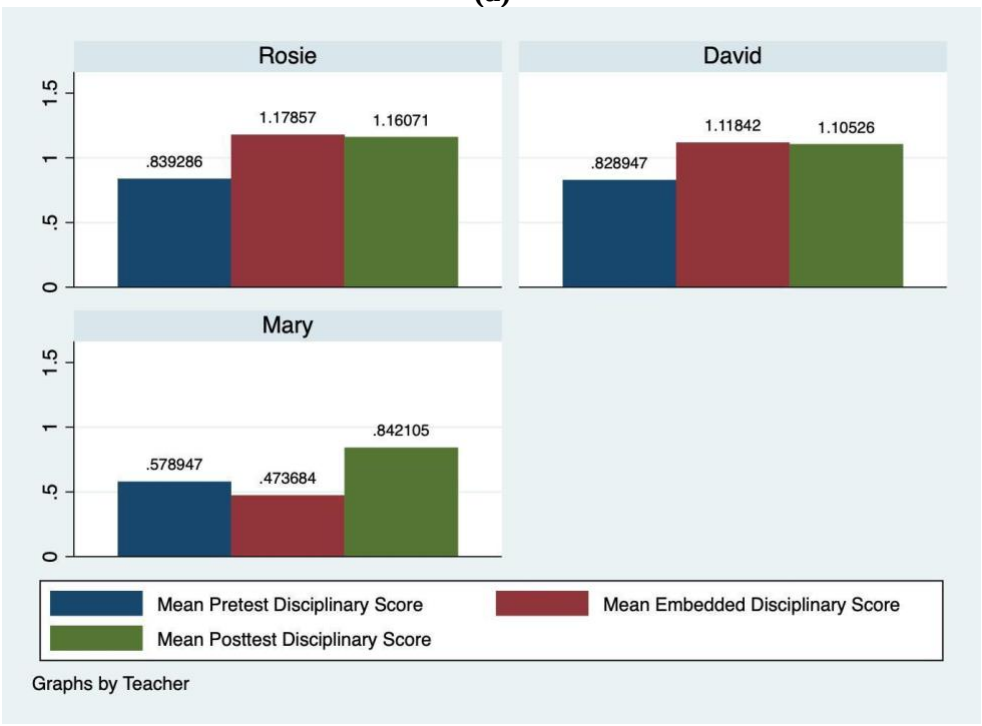
Student learning

Students made significant gains in their KI scores from pretest to posttest on justice (mean difference=0.371, $t(150)=6.91$, $p<0.001$), disciplinary (mean difference=0.291, $t(150)=5.13$, $p<0.001$), and KI scores (mean difference=0.583, $t(150)=8.26$, $p<0.001$). See Figure 4.4 for the mean KI, *disciplinary*, and *justice* scores for each teacher at each time point. The greatest score increases were in the justice domain, an area of focus for the teachers. This suggests the unit and teachers' instruction were effective in promoting students to connect ideas about the role past policies contribute to racial and socioeconomic disparities affect the ways people are impacted by climate change and pollution from emissions. While the increase was largest, teachers reflected that they still would have liked to see higher scores for students in the justice domain, closer to the scores they saw in the disciplinary domain. They had hoped that students were learning about the social justice issues just as much as they were learning about the typical disciplinary content. See Figure 4 for the mean KI, *justice*, and *disciplinary* scores at each time point.

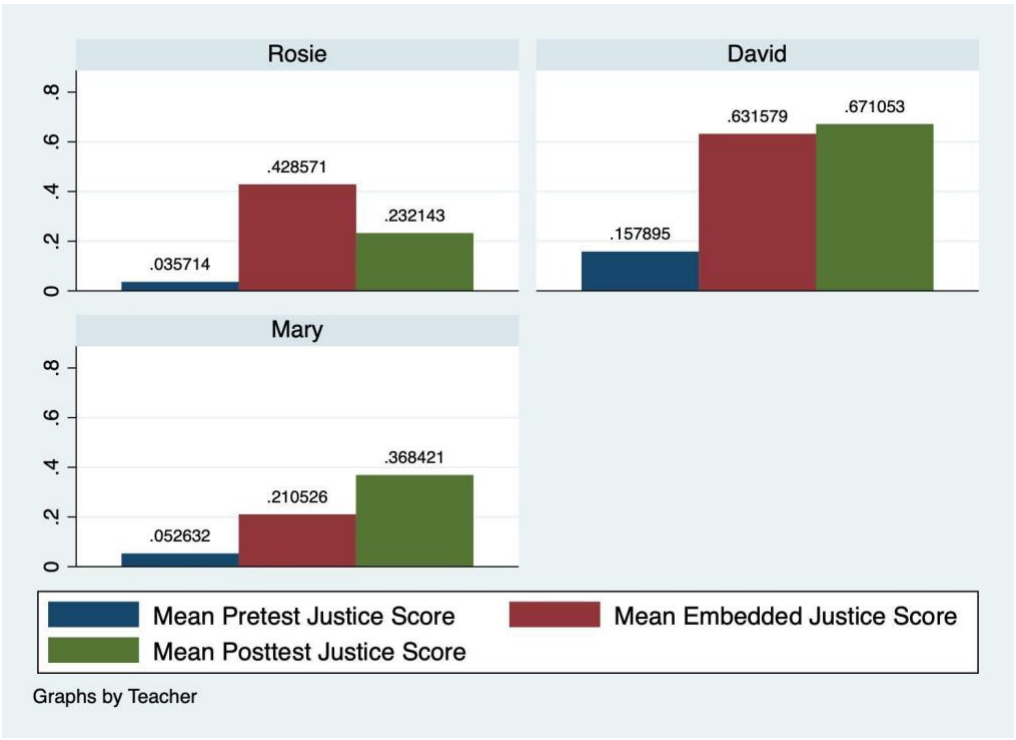
Looking at the change in students' scores from the end of the lesson focused on the justice issues to the posttest, we generally did not see significant gains (see Table 4.3). The exception is that Mary's students saw significant gains on the *disciplinary* score (mean difference=0.368, $t(18)=2.35$, $p=0.015$). These findings suggest that despite the teachers taking time to make sense of the report and considering their next instructional move, their interventions were insufficient to support their students to write more robust or elaborated explanations of the SJSI. There are many possible explanations that could contribute to this difference. For example, it is possible that students experienced fatigue from answering the questions so close together. Additionally, while the teacher report had the option to view both class level and individual student work the teachers primarily focused on the histograms displaying class level information. This resulted in the teachers thinking about instruction decisions at the level of the class. It is possible that students needed more personalized intervention. Further, one of the teachers offered suggestions to make the TAP more actionable. It is possible that with an improved design the teachers would be better able to plan interventions.


Impacts Item KI Scores by Teacher
Rosie
David
Mary
2.67857
3.23214
3.19643
2.85526
3.44737
3.5
2.21053
2.52632
2.73684
0
1
2
3
4
Mean Pretest KI
Mean Embedded KI
Mean Posttest KI
Graphs by Teacher

(a)


Rosie
David
Mary
.839286
1.17857
1.16071
.828947
1.11842
1.10526
.578947
.473684
.842105
0
.5
1
1.5
Mean Pretest Disciplinary Score
Mean Embedded Disciplinary Score
Mean Posttest Disciplinary Score
Graphs by Teacher

(b)



(c)

Figure 4.4. Mean (a) KI, (b) *disciplinary*, and (c) *justice* scores on the *Impacts* item for each teacher at pretest, embedded within the unit, and at posttest.

Table 4.3. Mean difference in score from pretest to posttest and from embedded to posttest for each score type for each teacher. The p-value for the difference is in parenthesis. Differences that are significant at the p=0.05 level are bolded.

Gain Type	*Rosie*	*David*	*Mary*
Pre to Post KI	0.52 (<0.001)	0.64 (<0.001)	0.53 (0.004)
Embedded to Post KI	-0.04 (0.610)	0.05 (0.288)	0.21 (0.107)
Pre to Post Justice	0.20 (<0.001)	0.51 (<0.001)	0.32 (0.005)
Embedded to Post Justice	-0.20 (0.024)	0.04 (0.284)	0.16 (0.094)
Pre to Post Disciplinary	0.32 (0.001)	0.28 (<0.001)	0.26 (0.086)
Embedded to Post Disciplinary	-0.02 (0.566)	-0.01 (0.582)	0.37 (0.015)

Discussion and Next Steps

We were able to successfully develop an AES model for an assessment item that prompts students to write explanations that integrate disciplinary and justice ideas that can be applied across unit contexts. The scores supported teacher reflection but might be better used to guide students. The scores supported plans for unit revision. Teachers endorsed the plan to refine the unit and use the scores to guide students to revise their responses.

Designing Actionable Dashboards for Teachers

Unsurprisingly, the teachers adapted our tools to suit their existing teaching practices, as is consistent with past work on teacher dashboards, including the TAP (Gerard et al., 2020; Wiley, Dimitriadis, & Linn, 2023). In some ways, we saw the teachers using the tools as we intended – to make pedagogical decisions about what to do in the next class period and reflect on their teaching and the curriculum for next school year. David and Mary both used the tools during instruction to monitor student progress, determine which students to check in with and to affirm their existing lesson plans. While none of the teachers used the recommended actions in the TAP as we intended, the tools provided them both with greater access to their students' ideas and whole class patterns of performance leading to the teachers. Rosie and Mary, in particular, used the information in the TAP to corroborate their plans to lead class discussions that encompassed many features of the KI framework: eliciting student ideas, providing opportunities for students to discover each other's ideas, and prompting students to distinguish whether their ideas hold explanatory power. For all teachers, the tools promoted reflection on their students' learning and how they would like to teach the unit in the future, consistent with how teachers used the TAP to guide their curriculum customization in Study 1 (Bradford & Gerard, 2021). Rosie's concern that she did not have insight into her students' thinking led her to think about the kinds of assessment she would like to use in the future to better uncover the degree to which her students were internalizing and connecting their ideas.

The ways the teachers leveraged the TAP and their feedback on the design underscore the importance of pedagogically grounded scoring models and dashboard designs. These teachers have been a part of the RPP for several years and have been developing strong pedagogical understanding of the KI framework. With that in mind, the tools were designed to foster use of that pedagogy. David and Mary were able to use their knowledge of the KI framework to support their interpretation of the scores displayed in the TAP. While Rosie is also familiar with the KI framework and often exhibits the KI tenets in her teaching practice, this did not translate to making the scores interpretable or actionable, perhaps in part because the *justice* and *disciplinary* scores were related to a new context and the corresponding scoring rubric was not as clear to her.

It is possible that additional time spent reviewing the item, student responses, and the scoring rubric during RPP workshops would support the teachers in planning how they will use the TAP and ensure that they have time available to do so in their lesson calendar. Doing so might also generate new design suggestions that can build upon the suggestions each teacher generated during our interviews. Further, as the teachers engage in RPP activities and further develop their pedagogical content knowledge (e.g., Magnusson, Krajcik, & Borko, 1999; Shulman, 1986) at the intersections of science and social justice, the RPP will collectively develop a better understanding of the ideas students are grappling with and how to respond to them.

We intend to revise the TAP in partnership with these teachers prior to using it again in the next school year. Given that each teacher has their own pedagogical approach that blends what

they have learned about KI and SJSP with the other pedagogical approaches they have cultivated over their teaching careers, we envision the possibility of designing an interactive and customizable TAP that enables each teacher to interact with the data and representations that they find most useful.

Future Directions

This work raises new issues about the evaluation of the AES models that have been developed for KI, *disciplinary* and *justice* scores. Further research on the generalization of AES models across similar contexts would be helpful. For example, we found limitations in our interpretation of the evaluation of each model based on whether it was trained on data from the Asthma context, the UHI context, or the combined dataset. This may stem from the sizes of the UHI and Asthma datasets. Using newly collected data, we could equalize the data sets and test this idea. Now that we have collected more student responses in the UHI unit context, we could hand annotate an equivalent number of responses from the UHI unit so the datasets are the same size. This would help determine whether it was the size of the training dataset or another factor that influenced the models' performance in each evaluation context. Another future direction concerns the interpretability of each model. Future work could use qualitative approaches to analyze whether there are differences in what each model finds important based on the training context.

Conclusion

To support teachers to center social justice in their science instruction we developed AES models to score student explanations of SJSI. We used the scores to design a teacher report, called the TAP, that provided teachers with class level distributions of scores, individual student responses, and recommended actions. We found that, as expected, teachers noticed the ideas their students held as well as ideas they needed additional opportunities to develop. Their reflections on the information in the TAP supported them to consider the plan for their next lesson. They also identified areas for instructional improvement by examining the results from the TAP across the unit.

Chapter 5: Conclusion

The studies presented in this dissertation are guided by the overarching research questions: *How can we leverage technology to support teachers in their efforts to be more responsive to the needs and ideas of their students?* Taken together, the three studies presented in this dissertation shed light on teachers' trajectories for customizing curriculum to be more responsive, their trajectories for teaching science for social justice, and their trajectories for leveraging technology as a support for their teaching practice. The findings have implications for expanding our understanding of Knowledge Integration pedagogy by integrating social justice principles and for the design of technologies that support teachers in principled customization.

Summary

Iterative Design of a Workshop to Support Teacher Customization of Curricula

We iteratively designed a professional development workshop intended to support customization by making the pedagogy behind our curriculum visible and engaging teachers in analysis of their students' work. We found that the activities designed to make KI visible were initially successful and, as they were improved, became more useful to the teachers. The representation in the first workshop made the instructional goals of each unit explicit and enabled teachers to articulate the connections to their own goals. The move to Google slides and the improvements in the representation provided a more robust view of the KI pedagogy, supported multiple perspectives on the unit, and increased opportunities for teachers to collaborate on customizations. Furthermore, refining the representation of the pedagogy strengthened teachers' ability to integrate their own activities into the unit and led to increased sophistication of the reflections on their own pedagogy as they customized the units

Our methods for making student work accessible increased the likelihood that teachers considered student work as valuable evidence to inform their customizations. This was especially true if the student work was from their own classroom and was directly related to their interactions with students while teaching. In addition, teachers reported that access to the class summary during instruction enabled them to build on their students' ideas. Further, the combination of the class summary and examples of their students' responses provided teachers with a coherent picture of their students' needs and shifted them away from a deficit view of students' ideas as misconceptions or wrong to a KI view of the value of building on student ideas to encourage coherent understanding.

These results illustrate the challenges and value of careful design of teacher workshops to support teaching customization of curriculum. They show that making the pedagogy visible when engaging teachers in customizing curricula has the potential to extend beyond the unit being customized. Teachers reported using the KI pedagogy in their own planning and to connect their offline activities to the online curriculum. These results show the benefit of making student work accessible to help teachers incorporate all their students' ideas rather than only those they recollect at the workshop. The results support viewing the customization process as a trajectory. It starts with ensuring that teachers feel ownership of the customization process. It continues by deepening understanding of the pedagogy behind the instructional design so that the participants integrate it into their own pedagogy. It culminates in connecting the pedagogy to the learning activities of the students. In this case, illustrated by a shift from a focus on addressing misconceptions to a focus on building on the nascent ideas developed by the learners.

Teacher development trajectories for integrating social justice and science

In this study we examined the development of three teachers' perspectives on their purpose and teaching practices for integrating social justice into science as they participated in RPP activities and taught middle school science units that integrated social justice issues over two years. We examined transcripts of teacher interviews from before and after each year of teaching. We also analyzed running transcripts and notes generated from the observation of one class period per day for each teacher during both years of the project. We also examined the ways they customized the units from year to year.

First, we examined teachers' perspectives on the purpose of integrating social justice and science by examining their articulation of their purpose during the interviews. We found that each of the teachers exhibited shifts in how they articulated their purpose for integrating social justice into science or in how their perspective aligned with instructional decisions that they made. For example, one teacher, David, began the project by viewing social justice as a means to make his science content more relevant for his students. By the second year of teaching, he expressed the view that students could only deeply learn about climate change if they also understood that it was entangled with larger social issues. While his initial stance of teaching science in contexts that are meaningful and relevant to students is an important part of justice-oriented science teaching, his perspective in the second year reflects a shift towards viewing science concepts and justice issues as inherently linked. Another teacher, Mary, expressed a stable perspective that it was critical to teach science in the context of social justice issues to support students to be prepared, civically engaged citizens. In the second year of teaching, she made deeper connections between this perspective and her experiences as a person of color, delving deeper into why her own experiences shape her purpose for teaching science in this way. Lastly, Rosie, also expressed a relatively stable perspective that it is a teacher's duty to help students understand how systems of oppression touch every facet of society, including science. In the second year, she more deeply connected her perspective to her practice by refining the final project she had designed for the Asthma unit. In the first year, she had given students a "lighter" option to focus on a final project that did not take up any of the social justice issues they had discussed in class. In the second year, she removed these options, requiring students to engage with both the science and social justice content.

We examined their pedagogical practices by examining classroom observations across the two years teaching the units. Several practices emerged as key for KI-experienced teachers to integrate social justice science pedagogy into their practice. On such practice is the KI practice of eliciting. Eliciting was a practice that each teacher engaged in more frequently during the second year of teaching. Further, the practice of eliciting co-occurred with nearly all of the SJSP practices we looked for, suggesting the importance of drawing out and building upon students' ideas and experiences for enacting justice-oriented science teaching. We also observed that teachers closely attended to the importance of building community in both years of teaching. This was a common practice for teachers in the first year and something they did with even greater frequency in the second. Teachers leveraged a wide range of KI and other teaching practices in service of building community. Lastly we noticed a shift in the emphasis and manner in which teachers fostered their students' critical consciousness and positioned them as transformative intellectuals. Like building community, teachers engaged all of the KI practices to find different ways to support their students' critical consciousness.

Designing learning analytics to support teachers to respond to students' integration of social justice and science ideas

We were able to successfully design a model for an assessment item that prompts students to write explanations that integrate disciplinary and justice ideas that can be applied across unit contexts. The scores supported teacher reflection, but might be better used to guide students. The scores supported plans for unit revision. Teachers endorsed the plan to refine the unit and use the scores to guide students to revise their responses. Using idea-detection models (e.g. Bradford et al., 2023) could enable the use of scores to directly provide students with responsive guidance in the moment while the score report might better serve teachers while refining and customizing curriculum between years of instruction.

Unsurprisingly, teachers adapted our tools to suit their existing teaching practices. In some ways, we saw the teachers using the tools as we intended. David and Mary both used the tools during instruction to monitor student progress, determine which students to check in with and to affirm their existing lesson plans. While they did not use the tools to revise their instructional plans as we intended, the tools provided them both with greater access to their students' ideas and whole class patterns of performance. For all teachers, the tools promoted reflection on their students' learning and how they would like to teach the unit in the future. Rosie's distrust in the AI-generated scores, paired with her overall concern that her assessments did not provide sufficient insight into her students' thinking led her to think about the kinds of assessment she would like to use in the future to better uncover the degree to which her students were internalizing and connecting their ideas.

With increased access to and awareness of generative AI, like Chat-GPT, we have an opportunity to address issues of pedagogy. So far, the drive to take advantage of these new technologies has led to an emphasis on technological questions of what we can do with AI in education or instructional questions like how we monitor and control student use, rather than questions of how to use AI to support teachers and students in the kinds of learning they value.

Discussion

This dissertation leverages three separate studies to address the question of how to design technologies that support teachers to be more responsive to the ideas, needs, cultural resources, and identities of their students. Across these studies, we examine how the designed technology tools that are integrated as part of the WISE ACE support teachers in different levels of responsiveness: in-the-moment, lesson-level, and unit-level (Kang, 2022), with the aim of supporting teachers to integrate social justice into their science teaching. Taken together, the studies reveal the importance of designing such technologies in sustained partnerships with teachers, the value of combining KI and SJSP as a pedagogical anchor for the partnership, and the utility of curriculum customization as a mechanism for joint learning in the partnership.

Designing technologies in partnership

In order to design technologies that support teachers to be responsive to their students' ideas, cultures and identities and needs, we need to design technologies that are pedagogically complementary to teachers' existing pedagogy. This means that these technologies need to be designed in partnership with teachers. We found a lot of success in supporting teachers to access and leverage their students' ideas, with assessment items that were clearly mapped to NGSS performance expectations. This is in part because this is the content expertise that teachers have been developing and is aligned with their knowledge of how to assess students, and what mastery

looks like for their disciplinary subjects. However, in the context of supporting teachers to respond to their students' ideas about social justice and how they link them to typical disciplinary ideas, we are still in new territory. In Study 2, we found that despite their eagerness to address social justice issues, our partner teachers were each at different starting points and still developing their understanding of their local social justice issues and the historical and political context surrounding them. This is unsurprising as these topics are rarely covered in teacher preparation programs (Sleeter, 2017) and is consistent with other work studying science teachers' understanding of culturally responsive science teaching (Brown & Crippen, 2017; Madkins &McKinney de Rosyton, 2019).

Working in partnership to construct a clearer picture of what it actually looks like for students to integrate social justice and science ideas is essential for being able to assess those ideas, recognize them in the classroom, and build on them through instruction. This is an ongoing process that raises many questions for the educators and researchers in our RPP. Working with students and teachers to identify what it looks like to integrate social justice and science ideas is critical for building on our beginning efforts to provide teachers with increased access to their ideas through AES and teacher reports. Study 3 reveals how teachers respond to technologies that provide insight into their students' thinking. This study can serve as a starting point for thinking about what it looks like when students are integrating their understanding of social justice issues with typical disciplinary concepts. However, as we saw in Study 1, it took a number of iterations of teachers developing familiarity with the items and how they map to the NGSS performance expectations that they're covering in their classroom for teachers to begin to leverage the ideas in their students expressed, rather than looking to pick out misconceptions. In Study 1, we also found how important it was to engage teachers in multiple customization opportunities to build their ownership of the technology-enhanced curriculum and to support their capacity to adapt it to meet their needs.

With the switch to integrating social justice issues, we are asking teachers to engage with new content areas that are often outside their realm of expertise. Time is required for them to develop sufficient familiarity to see what resources are present in students' ideas. Developing the ability to deepen the connections between the disciplinary context and the social justice science issues is an ongoing goal.

As teachers deepen their understanding of justice issues and the pedagogical approaches that support students to understand them in their classroom, personalizing technologies so that they are supportive and aligned to teachers' evolving pedagogical approach might be an avenue for supporting teachers to leverage AI-informed tools in their classrooms. A first step for doing so is to better understand how teachers envision the technology augmenting their practice. This would provide deeper insight into how we can develop technologies that are sufficiently flexible to support a range of teacher's visions. In Study 3, all the participating teachers were able to leverage the TAP for their own aims, however, these aims did not always take advantage of the just-in-time nature of the data available. Two of the teachers, Mary and David, had already integrated the use of the WISE teacher tools into their practice which might have supported them to envision how the TAP would support their teaching. While they did not take advantage of the recommended actions in that TAP, they were able to use the TAP to tweak the next day activities they had planned. It is possible that taking time to envision how the TAP would augment their teaching practice supported them to take action more readily in the moment of teaching.

Value of combining Knowledge Integration and Social Justice Science Pedagogy

Linking KI (Linn & Eylon, 2011) and SJSP (Morales-Doyle, 2017) empowers teachers and curriculum designers to make science accessible by enabling students to tangibly see how science can be used to achieve more just futures while also bringing a critical lens to the scientific enterprise. A social justice science pedagogy perspective enhances the way we interpret the tenets of Knowledge Integration. For example, it expands the ways we make science accessible. KI has always emphasized making science personally relevant (Linn, 2000), however, integrating SJSP expands this notion so that relevance also includes examining differential impacts and using science to take action in one's own community.

Bringing a KI perspective also enhances SJSP. KI is explicitly focused on supporting students to link and connect their ideas and experiences from both inside and outside the classroom. This makes it a particularly effective framework when the learning goal is to support students to connect their understanding of disciplinary issues with their understanding of social justice. Further, KI illuminates four key processes which provide an instructional road map to design activities that promote this integration.

Using these frameworks jointly for the design of curriculum supports students to investigate science issues that are locally relevant, tap into their budding sense of fairness and equity as adolescents, and supports a natural context in which students can use their science knowledge to take meaningful action. We are currently in a place design-wise where we are helping students discover how science can be used and taking action to raise awareness. Our next steps, as dictated by these frameworks, is to help students actually use science to make change.

Further, in Study 3, the frameworks guided meaningful technology development that supported both lesson-level and unit-level responsiveness. However, more work needs to be done to understand what integrated understanding of science and social justice looks like, what understandings are most important to teachers, and how best to assess that understanding. Doing so requires continued partnership between teachers and learning scientists, as well as seeking out the expertise of educators and researchers with deep understanding of social justice and cultural relevance. This will be a partnership of many learning curves, with the expertise of each kind of partner helping the others in different ways. As we collectively improve our understanding, we can strengthen the alignment of teacher-facing tools to better augment teacher practice and provide insights that are actionable, pedagogically-driven, and in service of practices that support students' to develop integrated understanding of science and social justice.

Curriculum customization as a mechanism for joint learning

Looking across the studies in this dissertation, we see a trajectory emerge that characterizes how teachers develop in their ability to customize curriculum. Prior work has shown that customization is an appropriate way to engage teachers providing their expertise to the development of curriculum (Ball & Cohen, 1996; Gerard, et al., 2011; Remillard, 2000; Goldman, Hmelo-Silver, & Kyza, 2022). This is a flexibly adaptive approach (Trautmann & MaKinster, 2010) that meets teachers where they are at in terms of their available time and their expertise. It allows researchers and curriculum developers to leverage the in-depth knowledge that teachers have of their students and of their communities without requiring teachers to devote more time than they have available by taking on the role of curriculum designer. Inviting teachers into customization through workshops and other professional development activities requires and promotes learning for both teachers and researchers/developers. Leveraging the KI framework to support our mutual learning, we found that, initially, teachers expressed surprise when we elicited

their perspectives to customize units to meet the needs of their particular students rather than prescribing an approach and emphasizing fidelity of implementation. This experience supported teachers to develop a sense of ownership over the curriculum.

As teachers became more comfortable customizing curriculum while engaged in customization workshops, they strengthened their pedagogical design capacity. The studies in this dissertation found that leveraging technology tools that make the pedagogy of the designed curriculum visible supported teachers to integrate their own pedagogical strengths with the pedagogical design intentions behind the curriculum. We noticed that increasingly drew on their students' thinking as evidence to inform those customization decisions. In attending to student thinking and their experiences both inside and outside the classroom, we observed that teachers began to shape their customizations to local issues that were of importance to their students. They aimed to engage students in experiences where they could use science as a tool for making injustice visible and making change in their communities. Because of the sensitive and localized nature of customizing that features social justice issues, teachers need to bring in additional information about their students' experiences and understandings of the world. We found that customization approaches are even more context dependent than when simply considering students' experiences with disciplinary phenomena. By engaging with teachers in the customization process, they learned more about local justice issues and built on the experiences of their students. In turn, the research team learned more about the contexts and issues that were meaningful to students. Collectively, we strengthened the curriculum and cultivated practices that better supported students to integrate their understanding of science and social justice issues.

Implications and future research

Designing for social justice science issues

Studies 2 and 3 put forth a combination of Knowledge Integration and Social Justice Science Pedagogy as a productive framework to design curriculum and assessments that integrate social justice and science. In order to support our partner teachers to integrate social justice into their science teaching, we need to expand topics covered so that teaching social justice sciences issues isn't just an interesting add on to one unit, but rather a core element across all content teaching. As the RPP continues, we seek to identify additional standards-aligned topics where we can connect to social justice science issues.

For example, we have already seen how one of our partner teachers, Mary, has begun to leverage multiple WISE units featuring social justice issues as well as connecting to justice in the other curricula she uses in her classroom. During the first year of the project, she taught two WISE units and in the second year she taught three. During class discussions while teaching the UHI unit, Mary supported her students to draw connections across the evidence they had examined in each unit to build a bigger picture of the influence of systemic racism in our society. Mary also participated in other programs focused on designing science lessons that highlight social justice issues. It is clear that Mary came to our project and RPP with a desire to infuse social justice into many of the science topics she teaches which likely supported her to make additional connections and encouraged her to teach multiple justice-centered WISE units. That said, her case offers an example of how continued engagement in the design, teaching, and reflection on such curriculum can support a teacher to build connections and infuse social justice into more and more of their science teaching.

We hypothesize that the more the RPP explores possible disciplinary and justice connections, the more readily we (both teachers and researchers) see examining social justice

issues as inherent to the study of science. To study this hypothesis, future work with our partner teachers could involve examining their teaching across an entire school year to see how they customize both WISE and other curricula to make connections to social justice science issues. We can also examine when and how they leverage teaching practices that integrate KI and SJSP across the units that they teach. Such studies will provide greater insight into how to cultivate an orientation toward and the practices essential to enact social justice science teaching. Further, as we expand the number of units available and the number of teachers who participate in the partnership in differing capacities, we create the conditions under which we can more systematically study the impact of particular partnership activities on teacher's perspectives and practices.

Enhancing partnerships to leverage teacher knowledge and advances in AI

We are still in the early stages of understanding how to assess students' knowledge integration of science and social justice issues. Study 3 put forth an example of an assessment, but the short essay produced by students did not satisfactorily capture the level of understanding most of the partner teachers believed their students held. Based on their observations of class discussions, the teachers often believed that their students had ideas that they either were not writing in the explanations or that were not detected by our autoscoring models. To better align with and leverage what teachers are attending to in the classroom, future work needs to explore how to improve the design process for assessments and corresponding technologies so teachers are in the loop without placing excessive demands on their time.

One approach that can be explored through the existing RPP activity structures is partnering with teachers to customize assessments and the corresponding TAP. By doing so alongside the existing process for reflecting on and customizing the units, we can better connect assessments and teacher tools to teachers' evolving perspectives on how to assess the integration of social justice and science ideas. This process would require us to work with each teacher to articulate their perspective on the kinds of assessment information that would be actionable for them given the affordances and constraints of their teaching environment. A possible tension that can emerge in the process is finding the balance between meeting teachers where they are while still designing assessments and tools that push teachers to advance their justice-oriented KI pedagogy.

A challenge for empowering teachers to customize the assessments, scoring models, and teacher tools will be establishing a pipeline to quickly customize the AI tools so that they capture what teachers find meaningful. One viable approach to doing this is to take advantage of recent advances in modeling techniques that leverage few-shot and zero-shot training methods. These methods leverage very small amounts of data to enable pre-trained models to learn new classification. Effective use of such approaches would enable us to update models in response to the ideas teachers observe in their classrooms. Beyond tailoring the tools to the teacher, another advantage of this approach is that it would enable us to localize our models to recognize the particular ways of knowing and modes of expression in each classroom. This would help ensure that models support teachers to elevate and leverage the unique ideas in their classrooms, rather than only representing the most frequent ideas. Future work can explore the degree to which customizing the tools supports teachers to use them during instruction. Further we can explore whether we are able to develop more accurate models that capture a wider range of the ideas and ways of expressing understanding in each classroom.

Exploring when to provide feedback to students and when to provide it to teachers

Given the range of AI-driven tools that are rapidly being developed and used in classrooms, it will be important to consider when it is most productive to leverage these tools to support teachers and when it is productive to directly provide feedback and support to students. In Study 3, the teachers used the information generated by our automated scoring models to validate their instructional plans and reflect on how to improve outcomes the next time they teach the unit. They were not, however, able to use the information to implement the activities we recommended in the TAP or design their own activities to further student understanding. This is understandable as teachers are under constant pressure to cover a wide range of content and might feel urgency to move on. As one of the Study 3 teachers, David, reflected while looking back at the TAP over the summer, "We just have like all these lingering questions at the end, and then we have to move on to the next thing. And that's just kind of the way we have so much packed into our freshman bio class. That it's just a bummer… they like started to make those connections, but like, there's definitely lingering questions and the milestone reports help trying to confirm where they're at ... [but] trying to reteach that? I didn't have that luxury."

While supporting teachers' reflection is a productive use of the TAP, it does not fully take advantage of the pace at which the automated scoring models make information about student learning available. The finding raises the question of when the information generated by AI tools is better used to directly guide students and when it is better to provide guidance to teachers. In future work with the UHI and Asthma units, I seek to explore the use of technologies that can complement the TAP by providing direct, in-the-moment guidance to students. Such technologies can support students while teachers attend to other priorities or take time to make sense of student progress. For example, in the case of the Impacts item, we can automatically suggest pedagogically-informed activities that engage students in making sense of the connections between disciplinary concepts and justice based on the scores generated by the AES models. This can engage students in additional opportunities for learning while providing time for the teacher to reflect on student progress and target the students most in need of support.

Another particularly promising approach to explore is the use of adaptive dialogs. Adaptive dialogs can help students build on their own ideas to deepen their understanding. The WISE RPP has recently begun leveraging NLP-driven idea detection models that can complement existing AES models. These idea detection models can be applied to student explanations to detect a wide range of the ideas and experiences that they are bringing to bear in their explanation. With these idea detection models, we can develop adaptive dialogs that are designed to provide guidance to students based on the ideas present in their explanation. While the idea-detection is done by the NLP models, the guidance is authored by researchers and teachers so that we can ensure that students receive pedagogically-grounded guidance. Early work with these adaptive dialogs suggests that they are effective for eliciting more of students' thinking and encouraging them to express a wider range of the ideas they hold about a phenomenon (Bradford et. al, 2023; Li et al., 2023; Holtmann et al., 2023). We found that this was particularly true for students whose initial explanations to an item contained primarily vague and descriptive ideas (Bradford et al., 2023). Given teachers' concerns that the *Impacts* item (and thus the automated scores) did not elicit the full range of students' understanding, the adaptive dialog might be a promising approach to support students to express more of their ideas.

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Appendix A

Supplemental tables for coding frequencies of classroom observations in Chapter 4.

Table A.1. Frequency of each SJSP and KI code for each teacher in each year. Darker green indicates greater frequency.

Codes	Mary, Year 1	Mary, Year 2	David, Year 1	David, Year 2	Rosie, Year 1	Rosie, Year 2
Read from unit	0	0	4	0	0	0
Customize unit	0	1	0	1	3	3
Share personal experience	5	8	0	1	4	2
Build community connections	3	7	3	7	18	23
Center emotions	0	1	0	0	6	6
Make systems of oppression visible	6	6	0	5	10	8
Guide students to distinguish actionable solutions	6	13	2	3	10	7
Position students as intellectual authorities	2	2	3	5	6	10
Ground learning in SJSI	2	3	1	5	3	0
Foreground local issues	2	0	3	9	7	6
Express high academic expectations	8	4	1	5	8	0
Discover	4	3	2	9	14	7
Distinguish	9	14	6	16	37	34
Elicit	11	19	5	12	34	43
Reflect/Connect	3	4	3	2	7	8
High-level KI reference	0	1	1	1	2	2

Table A.2. Comparison of KI and SJSP codes in the justice-foregrounded and disciplinary-foregrounded discussions for each teacher in each year. The frequency of each code is in parentheses. Only codes that occurred more than once are included.

	Justice-foregrounded episode		Disciplinary-foregrounded episode	
Teacher	KI Codes	SJSP Codes	KI Codes	SJSP Codes
Rosie, year 1	Distinguish (6) Elicit (3)	Foster critical consciousness (7) Build community connections (5)	Elicit (8)	Foreground local issues (4) Build community connections (3)
Rosie, year 2	Elicit (8) Distinguish (6)	Build community connections (7) Foster critical consciousness (6) Center emotions (6) Position students as intellectual authorities (5)	Elicit (7) Distinguish (3)	Foreground local issues (3) Build community connections (2)
Rosie's main shift: Greater emphasis on eliciting student ideas and centering emotions during the justice-foregrounded episode in Year 2				
Mary, year 1	Elicit (4) Distinguish (4)	Foster critical consciousness (5) Position students as transformative intellectuals (3) Foreground local issues (2)		Maintain high academic expectation (3)
Mary, year 2	Elicit (3) Distinguish (3) Connect (3)	Foster critical consciousness (5) Position students as transformative intellectuals (2) Ground learning in SJSI (2)	Elicit (2) Distinguish (2)	Position students as transformative intellectuals (2)
Mary's main shift: Positioning students as transformative intellectuals in both justice- and disciplinary-foregrounded episodes in Year 2				
David year 1	Elicit (2)	Foreground local issues (2)	Distinguish (2)	Position students as transformative intellectuals (2)
David, year 2		Ground learning in SJSI (2) Maintain high academic expectations (2)	Distinguish (3) Discover (2)	Build community connections (2)
David's main shift: Emphasize local justice issues, rather than just local knowledge, in justice-foregrounded episode in Year 2				