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The quest for sustainable futures: designing transformative learning spaces with multilingual Black, Brown, and Latinx young people through critical response-ability

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Abstract

In an era of global climate change, intertwined with social and ecological predation, there is growing recognition of the importance of building socially, environmentally, culturally pluralistic, just and sustainable futures. Yet many of the calls for reform and discourses around sustainability are authored and defined through top-down approaches, by those who have power, privilege, and cognitive authority, and excludes the voices, identities, and epistemologies of those in the margins. In this paper we argue for the need to design and develop transformative learning ecologies that explicitly position the diverse voices of youth from nondominant communities as central to re-defining and re-envisioning relationally just, pluralistic, and sustainable futures. To this end, we seek to provide examples from participatory design-based learning ecologies to illustrate the centering of middle school youth voices and agencies from multilingual Black, Brown, and Latinx communities through critical response-ability. These examples highlight how these youth grapple with the uncertain landscapes of sustainability in their communities and provide counter-narratives to traditional deficit-based discourses and youth empowerment. We draw on what we have learned from multilingual youth to offer some suggestions for designing transformative learning ecologies situated within the framework of critical-response-ability in the quest for sustainable, thriving, and just futures.

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Dilemmas of changing times

The world is experiencing an increasingly warmer planet where changes in weather patterns, melting glaciers and shifts in migration are inextricably linked with social and economic inequalities. The impact of industrialized practices, changes in migration patterns of plants and animals, and corresponding shifts in viral and bacterial transmission have adversely affected all species. In addition, the impact and historical legacies of colonization, settler-colonization, slavery and white supremacy are still deeply entrenched and felt across all social, ecological, and natural systems of life. We live in a society where Black people can be targeted and killed at the hands of the police for simply jogging in a white neighborhood (#sayhisname #ahmaudarbery). More than ever, or as always, we are seeing how these injustices, whether racial, environmental, social, or health related, are disproportionately affecting the most vulnerable communities and young people from racially, linguistically, and socioeconomically marginalized groups. As described by Fikile Nxumalo (2020) "current environmental challenges of the Anthropocene are intimately connected to past and present colonial and racial binaries that have prioritized certain humans' dominion over the more-than-human world in extractive and exploitative relationships" (p. 536). Current issues such as climate change, systemic racism, and the COVID-19 pandemic once again remind us that we are far away from building environmentally, socially, culturally sustainable, just, and thriving presents and futures—a world in which all humans and more-than-human flourish.

In a context of science education, research shows that these challenges have yet to translate into designs of learning ecologies that are sustainable, thriving, just, and inclusive of diverse voices, identities, and epistemologies (Bang, 2020). Put another way, issues related to environmental and social injustices manifest themselves not only at the macro planetary level, but also include meso and micro cognitive and epistemological levels, where modes of ethical and political engagement continue to be figured from white, Eurocentric, and nature/culture binary perspectives. In this paper, we begin with a discussion of sustainability, racial and environmental injustices and how these issues are figured and reflected in discourses about youth empowerment, social justice and science education. In doing so, we speak to the inadequacies of Eurocentric and Western epistemologies to tackle challenges brought by the Anthropocene, and subsequent erasure of Black, non-white, and Indigenous knowledge systems that continue to manifest themselves in dehumanization and deficit constructions of youth from minoritized communities. Instead, we engage with Indigenous, Black, feminist, and other Subjugated onto-epistemologies and axiologies of relationality, which inspire us to situate our work within the notion of critical response-ability. To this end, we consider the potential for creating learning spaces situated within critical response-ability, where multilingual Black, Brown, and Latinx youth from non-dominant communities, whose voices have been historically excluded and ignored from defining and solving complex problems, can author their identities, skills, and epistemologies as they tackle and solve multifaceted problems facing their communities and the world at large. Unlike Western human-centered notions of responsibility, we define critical response-ability as an onto-epistemological and axiological position of mutual respect and reciprocal relations "include[ing] ethical, practical, systematic, adaptive ways of flourishing together and dying well together with more-than-human relatives" (Nxumalo, 2020, p. 563). Critical response-ability is less about teaching how to be responsible or "empowered" individuals toward nature; it is more about fostering "relational accountability" and opening up possibilities for rendering one another capable in responsiveness, learning, being/becoming,

and participating in worldmaking as human and more-than-human collectives (Wilson & Wilson, 1998, p. 157). This notion of critical response-ability disrupts existing cognitive boundaries in terms of whose voices and epistemologies are rendered legitimate in envisioning and creating relationally sustainable and thriving futures for all. In this paper we provide two examples of design spaces for sustainability, framed in terms of locations of possibility for fostering critical response-ability (Brandt, 2008). These are transformative spaces where young people from non-dominant families and community members use science to collectively engage in decision-making and "relational accountability" (Tuck & McKenzie, 2015). They raise critical questions about social and environmental injustices in their communities, and question taken-for-granted assumptions about nature-culture binaries (Hufnagel, Kelly & Henderson, 2018) and the cultural neutrality of everyday technologies and practices (Sengupta, 2020). In a time when life on a planetary scale is threatened by diminishing air quality, viruses and human-induced impacts of fracking, these two examples afford opportunities for re-thinking sustainability and the design of learning ecologies in ways that reframe empowerment in terms of critical response-ability.

What do we mean by sustainability?

Sustainability is a complex concept, and its meaning may vary across different disciplines and spheres of influence. The most commonly accepted definition comes from the United Nations World Commission on Environment and Development: Our Common Future (1987) report in which sustainability is defined as a process "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 15). This dominant view defines sustainability by centering the needs of "humans." However, situated within the views of "human-supremacy," this human-centered notion of sustainability is largely challenged and critiqued as being rooted in Western humanism, binary thinking, and anthropocentric views of the world, which historically have served to dehumanize and objectify women, children, Blacks, Indigenous peoples, and nature, or those who are deemed as "non-human" or "less-than-human" by dominant groups (Kayumova, McGuire, & Cardello, 2019). Much of this critique of human-supremacy and exceptionalism, and anthropocentric views of the world is often currently reconfigured through posthumanist and feminist new materialist scholarships by focusing on "a universalized human," and the entangled nature of ontology and epistemology, nature and culture, and by critiquing Western binaries (Barad, 2012). Yet, much of this scholarship fails to recognize that for many Black, Brown, Indigenous and other Subjugated communities, human and more-than-human relations have been central, and categories of ontology, epistemology, and axiology have never been separate. Consequently, as Sylvia Wynter (2015) explained, the intellectual task cannot only be about questioning human exceptionalism and the binaries associated with human/non-human dichotomies, but also about demythifying the assumption of a universalized human claimed by postmodern scholarship, which resulted in dehumanization of, and continues to dehumanize and erase, Black, Indigenous and other Subjugated groups from the very category of human (Nxumalo, 2020). As we mentioned, what is considered as non-human, such as land, water, wind, plants and people's relationships to Earth has always been sacred for many Indigenous groups, although these onto-epistemological and axiological positions have been traditionally delegitimized within dominant Eurocentric and Western academic thinking. Elsewhere, we (Kayumova & Buxton, 2021) describe how this shift toward posthumanism, or what is known as an

ontological turn, is more of a turn in Western academic thinking to a place "where Indigenous people have always been" (Tuhiwai Smith, Tuck & Wayne 2018, p. 15). Moreover, as Arturo Escobar (2018) noted, these existing "ontological struggles" are consistently configured by many Black, Indigenous or Subjugated communities who reject distinctions between individual and community, natural and cultural, and similar binaries by focusing on praxis of interconnectedness, relational accountability, and self-determination.

Accordingly, we argue that there is a need to figure onto-epistemological and axiologically intertwined understandings of sustainability situated within diverse community perspectives. To this end, we engage with Black and Indigenous onto-epistemologies of "relational accountability" (Wilson & Wilson, 1998, p. 157) and response-ability, through which we are inspired to figure the notion of sustainability as an extended set of relations and interactions between social, cultural, economic, and environmental justice to achieve healthy, thriving, and diverse human and more-than-human collectives. This notion of sustainability recognizes the need for praxis which includes systems and complexity thinking similar to what hooks (2000) describes as "a way of thinking and behaving that honors principles of inter-being and interconnectedness" (p. 77). In the section that follows, we articulate how this notion of praxis might be embedded in the design of learning ecologies through the conception of critical response-ability.

From empowerment to critical response-ability

In the context of science teaching and learning, a praxis based vision of sustainability requires us to rethink the ways in which diverse cultures, onto-epistemologies, identities, knowledge systems, and experiences of diverse young people and communities are integral to achieving interconnected, response-able, respectful, and relationally accountable science. At a surface level, this vision may not seem to be much different from widespread rhetoric about the importance of engaging and empowering young people in science, especially those from non-dominant Black, Brown, Indigenous, and Latinx communities, so that they can become "scientifically literate," participate in formulating solutions to the existing social and environmental challenges the world is facing. However, similar to notions of grit or tenacity, the idea of empowerment has become a racialized term that perpetuates racist narratives about nondominant communities and "normalizes" their condition. One of the first iterations of empowerment can be traced back to psychologist Julian Rappapon (1984, p. 3), who described it as a practical power or "a process: the mechanism by which people, organizations, and communities gain mastery over their lives." We argue that nondominant communities experience injustices, be it racial, educational, environmental, or health due to systemic inequities rather than a lack of "agency," "tenacity," "resilience" or "power" (see Kayumova, McGuire, & Cardello, 2019). In the context of science teaching and learning, this translates into deficit-centered scholarship which suggests that young people simply are not motivated or interested in learning science and fails to acknowledge the systemic inequities at the root of these problems. For instance, decades of research about schooling and science education, show how schools operate from dominant cultural, linguistic, and epistemic perspectives and practices, which not only disproportionately disadvantage young people from nondominant communities but also disenfranchises them, their social identities, language, culture and ways of being and knowing (Kayumova and Harper, 2020).

These concerns are also reflective of the work of scholars of color (Adams, Gupta, & DeFelice, 2012), Black, Brown, Indigenous, and Latinx women (Gutiérrez, 2017) and feminist scientists (Barad, 2007). These scholars have been calling for more expansive and epistemologically pluralistic and expansive views of science and science curriculum, teaching, and learning that takes into consideration historical and sociopolitical issues. We join these scholars in arguing that we need to rethink the role of science and science education in designing a sustainable and just society and recognize that young people today are more than capable of engaging in this quest based on their everyday experiences, identities, cultures, knowing and being (Holbert, Dando, & Correa, 2020). From this perspective, perhaps one possible re-framing of empowerment is critical response-ability. Karen Barad (2007, p. 393) explains response-ability as a stance which is "not about right response…but about responsibility and account-ability for the lively relationalities of becoming of which we are a part." However, this notion of response-ability is often understood from posthumanist and new materialism perspectives, which has been critiqued to do away with or "dissolve" human and flatten the existing diversity, while many Subjugated and non-dominant communities continue to fight for the recognition of their humanity, voice, and dignity. Thus, this desire to "dissolve" human seems to be situated in a privileged position, or more precisely stems from White privilege. Science, technology, mathematics and engineering disciplines, broadly construed as STEM, already carry similarly universalizing and racist historical legacies, which, as Rochelle Gutiérrez (2018) cogently argues, have already been felt and experienced to be dehumanizing for many Latinx, Indigenous and Black communities. The argument is that while educational rhetoric emphasizes the importance of supporting youth from minoritized backgrounds in their struggles to be successful in school science, efforts to accomplish have often been situated within assimilative approaches to learning and resulted in inequitable experiences for youth, including erasure, delegitimization, and deficit-based constructions of diverse cultures, language repertoires, and knowledge systems. This can be seen, for example, in normative and Western epistemologies of science and definitions of what it means to be a scientist that tend to disenfranchise other cultural and everyday ways of engaging in scientific sense making and relating to a world that youth from diverse backgrounds may bring to in/formal learning spaces. Thus, it is not enough to simply "support" youth in their everyday science endeavors. Our proposed conceptualization of critical-response-ability includes what Gutiérrez describes as rehumanizing policies, practices, and measures that celebrate the full humanity of Black, Brown, Latinx, and Indigenous youth and youth from other Subjugated communities, their culture, and epistemologies in everyday interactions, relationships, connections and emotions such as joy and belonging. This process of rehumanizing, as described by Gutiérrez, is an active, on-going, explicit and relational effort to re-define what it means to feel comfortable with and connected to issues engaged within mathematics and science fields, in ways which embrace the experiences and full humanity of youth in the co-construction and co-production of knowledge. Shifting our pedagogies toward rehumanizing practices, also teaches us about inter-connectedness, ethics, care, relational accountability and respect toward humans and more-than-human collectives. Based on Gutiérrez's notion of rehumanizing, we conceptualize critical response-ability as a praxis for "the cultivation of collective knowing, desiring, being and making-with so that we render each other capable" (Murris & Bozalek, 2019, p. 11). From this perspective, critical response-ability entails creating locations of possibility for the design of socially, culturally, environmentally sustainable and just learning contexts where Black, Brown, Latinx, and Indigenous young people are recognized

as authors and owners of their existing and emerging knowledge that they co-construct in affective and embodied ways within the complex web of human and more-than-human relations (Nxumalo, 2020). These are spaces of collective transformations where youth engage in learning science and sustainability through relational perspectives and acknowledge entangled relations of humans and more-than-humans, as they tap into each other's humanity, history, culture, and knowledge in ways that challenge normativity (Love, 2019). This process eliminates status differences between humans and more-than-humans and cultivates relational accountability as well as equity among adults and youth alike (DiGiacomo & Gutiérrez, 2016). Thus, through the lens of critical response-ability perspective on designing learning spaces we emphasize the interplay between the natural, social, cultural, and political systems in the co-construction of meaningful and transformative learning spaces. These design-based learning ecologies support youths' complex, emergent and relational sense-making in ways that enable them to occupy positions of critical thinkers and problems solvers about the systems that underpin their everyday lives.

In the section that follows, we present two examples of design-based learning ecologies that constitute a "location of possibility" for designing sustainability and critical responsibility, a type of transformative space where students, teachers, parents and other community members can use their everyday and cultural knowledge to engage in productive scientific inquiry. As transformative spaces, these locations of possibility aim to represent critically response-able ways of generating nuanced understandings of sustainability which are "grounded in a historical and political understanding of the conditions and circumstances confronted by non-White communities" (Brandt, 2008, p. 719). Both examples reflect tensions that are deeply rooted in sociopolitical and historical arrangements of time, space, and place that are not void of cultural narrative (Fig. 1).

Examples of learning ecologies centered around critical response-ability

Tackling environmental issues with multilingual Black and Brown young people

In this example we highlight a longitudinal program, STEAM Your Way to College, which was designed with, and for, multilingual Black and Brown youth from local middle schools located in the Gateway Cities in Southern Massachusetts. The majority of young people participated in the program identified themselves as belonging to Black and Brown communities of Latinx, Cape Verdean, and Portuguese backgrounds. The program has included multilingual speakers of Spanish, Portuguese, Cape Verdean Creole, Haitian Creole, French, Arabic, and English. The guiding research purpose of STEAM Your Way to College was to explore the potential relationships between young people's science identity trajectories and learning ecologies in ways which positioned and recognized them as "advantaged based on their culture, language, home, and community knowledge." The program was designed around the idea that it is not enough to do "just good" or robust science with multilingual young people—there also has to be an explicit rejection of deficit-driven discourses about cultures and language of youth who come from Black, Brown, and Latinx communities. This asset-based lens stands in stark contrast to racialized and politically "neutral" ideologies which cast deficits on culture, identity, and multilingual repertoires of diverse Black and Brown young people and seek to assimilate them to dominant ways of

Fig. 1 Young people as critical research partners (junior researcher) are working with doctoral students, high-school mentors, and teachers/researchers (research–mentors)

knowing and being—as quickly as possible—often viewing their background as a problem to be solved (Kayumova & Harper, 2020). As a part of the program, young people were positioned as critical-research partners, and together with science teachers, graduate students, and university professors investigated topics related to environmental issues in their own local communities (from here on we refer to this group as collective, we).

Communities living in Gateway cities are confronted with legacies of post-industrial activities that have resulted in persistent economic, social, and environmental challenges characterized by hazardous waste sites, ecological pollution, contamination, and lack of sustainable jobs. For example, Gateway cities contain a disproportionate number of hazardous waste sites (sometimes referred to as "Superfund" sites or "Brownfields") that contain sediment contaminated with large amounts of polychlorinated biphenyls (PCBs). PCBs are long-lasting in the environment and cancer causing. These materials have been found in fish and other wildlife in the area at levels deemed toxic. The hazardous waste sites in these cities include the land underlying one of the major high schools and a middle school, both built on the footprint of a previous dump with various toxic chemicals. The environmental degradations in Gateway cities provide an example how social, racial, economic, political, and environmental issues are interconnected. However, the process of identifying and dealing with hazardous waste sites and environmental issues is very much a top-down process. Once a problem is raised by the local community, it is often the case that either the state or federal authorities along with university researchers, move in to assess the issue, diagnose the problem, create an ultimate solution, and then implement that solution on behalf of the local community (for more about detials of this context see Kayumova, McGuire, & Cardello, 2019). Although local meetings and input seem to be a part of the process, the ultimate decision-making authority rests outside the purview of the local community. As such the ability of local voices to be an integral part in the process of "remediating" the local land is muted. This top-down approach not only controls the narrative about local issues, but also diminishes community efforts for self-determination and their sense of agency and power. It is often the case that top-down approaches target the community in terms of putting the blame and responsibility on local people, such as telling the local community they are wrong in how they act (for example, fishing in "contaminated" areas of the harbor) (see Kayumova, McGuire, & Cardello, 2019). This creates a situation where science comes into conflict with local community priorities. Thus, the history of industrialization

Fig. 2 In the first picture, one of the critical research partners is participating in a design session and engaged in a making activity, while in the next session he takes on the role of observer and video recorder

Fig. 3 Young people, teachers and mentors are playing a game modeling air particles and air filters

and manufacturing in these local areas present a context for thinking about how science learning ecologies should, and can be, designed in ways that are informed by the experiences and priorities of the local community.

In acknowledging the criticality of communities' history, culture, and knowledge, we aimed at designing learning ecologies situated in the notion of critical response-ability, which was about opening up spaces of deep respect and care for young people's everyday identities, onto-epistemologies, axiologies and heterogeneous sense-making in the context of their lived experiences. To this end, youth were positioned as authors and epistemic agents of their learning, as together we engaged in research and sense-making practices centered around themes of systems thinking and sustainability. In addition, the program drew on participatory research design (Bang & Vossoughi, 2016), particularly its focus on

transforming "role re-mediations" between researchers and project participants. To eschew traditional hierarchies in status and roles, multilingual young people were positioned as critical research partners who could easily and fluidly switch their roles and responsibilities throughout the program (Figs. 2, 3).

Praxis of thinking and figuring air-quality

The STEAM longitudional program has included multiple and interconnected Science, Technology, Engineering and Art and Design sessions, each built on concepts of sustainability, systems thinking, and social and environmental justice. These major concepts were simple enough to be portrayed by a single word, yet rich enough to be explored over the course of a 2-week summer program, which has continued through subsequent academic years. Each year, youth, teachers, and researchers have participated in transdisciplinary sessions, which centered around research and sense-making about phenomena in local contexts and their entanglement with social, cultural, and political systems. In these sessions, young people and adults worked together in making and designing artifacts, which were tangible outcomes of their authoring, such as smart air filtration devices, food preservation boxes. Young people, teachers/instructors, doctoral students, and high school mentors, and university professors worked as co-designers and research partners to collect, model, and interpret data from local communities and in the context of their inquiries (Fig. 1).

For example, in the first year of the program, critical research partners found the issue of air pollution and air quality to be integral to the areas and communities where we lived. As critical research partners engaged in sense-making processes around air pollution and its impact on people, communities and the environment, we settled on designing environmentally friendly, smart, and sustainable air filtration devices. We collectively asked questions such as what kinds of practices and systems in place result in air pollution and environmental injustices? What can we do to help our communities and people who are caught up in these resulting injustices? Critical research partners engaged in market analysis and found that effective air filters were not only unaffordable and expensive, but also many of them either did not work well or did not use environmentally sustainable products. In the bioengineering research session of the program critical research partners explored existing filtration systems in the human body and in nature, and how they functioned. We asked questions such as: what kinds of filtration systems exist in our bodies and nature? How do they work? How can we design and develop air filtration systems that emulate the ones in our bodies and nature? As we engaged in exploring how filtering systems in the human body work, our questions reflected inquiries such as: What would a smart and sustainable air filtering system entail? How can we design filtration systems in ways that can detect and deter harmful particles in the air? Designing and making of artifacts were an important aspect of the inquiry process as multilingual young people authored and shared their knowledge with family, friends, school, and community. Beyond that, critical response-ability was key for the interactions and relations within this learning ecology: honoring and privileging young people's diverse social identities, epistemologies and languages, as well as their rights for self-determination and self-expression, were key aspects of these spaces. For example, earlier on in the program we found that students would frequently pause, saying, for example, "I don't know how to say it in English," or "I am not a science person," or "I am not good at this." In these instances, instead of "telling" them what to do or how to be, we engaged in deconstructing normative terms and understanding, and invited everyone to express their social selves and use home or community languages in ways that made

sense by engaging in translanguaging and multi-modal communicative practices (e.g., act it out, draw it). We often translanguaged, code-switched, and used our mobile devices to translate or help one another with communication. We used various ways of knowing as "accepting the validity of multiple ways of knowing and thinking," and taking this one step further, we sought to not only accept, but celebrate young people's multiplicities of practices and social, cultural, and linguistic identities and position them as assets (Turkle & Papert, 1990, p. 161). In all interactions, multilingual young people were positioned as knowledgeable and capable authors and designers of their learning and were encouraged to use multiple, culturally heterogenous and embodied ways of knowing to make sense of various phenomena. For example, in order to make sense of how particles travel through air filters, critical research partners used shirts and attached various sized balloons with Velcro to model the flow of various particulate matters such as dust, smoke, mold, pollen, through a filtration system. We used our bodies to model the behavior of particles, the air, and the filters, as some students ran through a maze (demarcated by cones), while their peers used pool noodles, lightweight cylindrically shaped pieces of foam, to whack off the different size and color balloons. As some of the particles would get through the pool of noodles, we increased the numbers and tightness of noodles to capture smaller particles. In this way, together, we embodied various components of an air filtration system. Throughout the experience, we noticed instances in which boundaries of student and instructor roles became more porous. We drew on these kinds of initial engagements with science concepts and sensemaking in service of disrupting dominant cultural identity models of what it means to do science and to be a scientist (Carlone, Haun-Frank & Webb, 2011). These kinds of engagements were followed by brainstorming and analyzing ideas, establishing criteria and constraints about materials and design features, and drawing and creating prototypes of "smart" air filtration systems (Fig. 4).

At the end of summer program, young people presented their artifacts and expressed how social, economic, and environmental systems of their homes, schools, communities, and cities were intertwined with each other, and how decisions and actions made on behalf of people and places were consequential to the health and vitalities of present and future ecosystems. Presentations were done in multiple languages including Spanish and Portuguese. Critical research partners took on roles of translators for community and family members, as well as researchers, journalists, and local industry representatives.
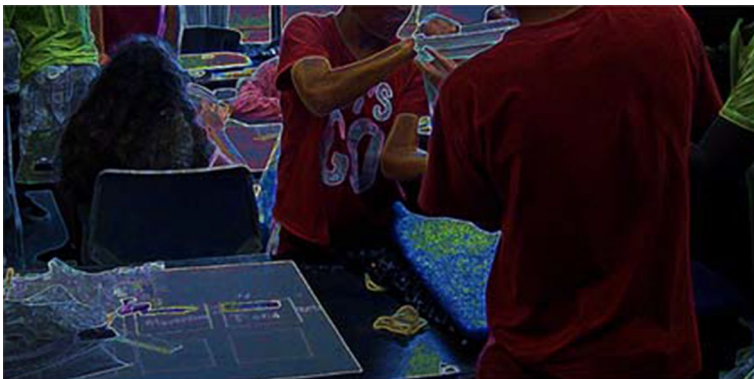

Fig. 4 Young people are designing their smart air filtration systems

Connecting students to their community: sustainability along the border

The Systems Academy for Young Engineering Scientists (SAYS) began as a summer enrichment program for rising 5th and 6th grade students from Latinx backgrounds from a rural Texas border town community. With the discovery of natural gas in the Eagle Ford shale formation, and the advent of fracking, the community seemingly overnight was transformed from its small-town atmosphere into a thriving hub of economic activity centered around the petroleum industry. At the center of this economic activity was fracking, a controversial drilling practice used to extract petroleum (oil) or natural gas from layers of shale deep within the Earth. In short time, temporary housing facilities known as "man-caves" were rapidly constructed alongside other housing for family members. "Water for Sale" signs were soon commonplace as the fracking continued to have an impact on the quality and availability of water. New roads were built to accommodate the oil tankers transporting the natural gas. Amidst this context of rapid economic and social change, education for sustainability became a central theme of the SAYS academy. In the initial year of this summer program, the curriculum focused on mathematics, watersheds and systems thinking. This was followed by an emphasis on robotics, physics and petroleum engineering. By the third year of the program, teachers were seeking a way to "broaden the goals of the program and realize the transformative potential of education (Tippins, Pate, Britton & Ammons, 2015, p. 77). Teachers and students together settled on the theme of "fracking" and decided to organize the summer academy around a central question: How can we create a sustainable community for future generations?

The activities of the SAYS academy were multi-faceted with interactions and experiences occurring across a multi-age community of learners. Teachers and students alike were already aware of some of the issues associated with the petroleum industry in the community. Together, we set out to become more informed about the practice of fracking in the local environment. We began to ask uncomfortable questions as we engaged in perspective making, an aspect of systems thinking which emphasizes the importance of entertaining diverse ideas (Pate, Guerrero & Dobie, 2015). We conducted rapid biodiversity surveys of flora and fauna in the community. We learned about fossil fuels, natural gas, oil traps, core sampling, petroleum products, earthquakes and petroleum engineering as a system. Through hands-on sensemaking experiences with core sampling and robots in the oil field, we engaged in exploring and learning about the geological processes important to fracking. Youth brainstormed, made models, learned how to build and program robots, and used NXT Lego Mindstorms robots to create oil field simulations. We engaged in mapping activities to understand the role of water as a resource shared across international borders. In the process, we acknowledged and shared with another our own life histories, including relationships to bodies of water such as the Rio Grande River. Additionally, we interviewed community members about their experiences with water quality and fracking. We listened to the concerns of the community expressed through their stories about possible chemical contamination of water or disposal of wastewater resulting from the fracking process. Finally, in order to entertain diverse perspectives, we invited individuals from the petroleum industry to speak with our group of students and teachers.

Systems thinking and systems dynamics were an over-arching organizing principle for the SAYS academy. Using systems thinking as a guide, students initially made observations and together we asked, "What is happening in our community?" We then turned to patterns of behavior to focus on events that were not so readily visible, asking questions such as "What are the trends?" and "What changes have occurred?" In order to examine

the trends, we built models using STELLA software which enabled us to make calculations about the quantity of oil left in the Eagle Ford reserve and predictions about how long it might last. As we continued engaging in systems thinking, we focused on the structure of the system and designed causal loops, connection circles and stock flow maps. Students also created graphs to illustrate the behavior of the oil reserve stock. The graphs illustrated how long the reserves would last based on different percentages of oil recovered. We were shocked when the model predicted the oil reserves would last 39 years; representatives from the oil industry had shared a number twice as long with us. This became an occasion to consider the idea that models are not neutral, and that they are dependent on the numbers that are input into them (Wilkerson-Jerde & Wilensky, 2015). In this sense, the emerging narrative surrounding issues of fracking in the community were no longer one controlled solely by outside experts from the petroleum industry. Collectively, students and teachers were authors of their existing and emerging knowledge in a space where relational accountability, care, and respect flourished.

A culminating activity of the SAYS academy was the townhall meeting organized by students and teachers for the community. During the meeting, youth shared what they had learned about the petroleum industry and made sure to include multiple perspectives. We arranged for translators for the Spanish-only speaking members of the community. Students answered a myriad of questions ranging from "what can we do about sinkholes?" to "how can we test the quality of our water?" As young adolescents, it was evident that they were positioned as informed decision-makers who had much to contribute to their community. The SAYS academy was not without tensions and paradoxes—after all, the livelihoods of the majority of students' and teachers' families were intertwined with the petroleum industry. In spite of this, the students and teachers, as authors of their own knowledge, became the catalysts for a larger community conversation about the resilience of the community. In a time when conservationist and preservationist ideologies have dominated approaches to education for sustainability, the SAYS academy provided us with opportunities to reflect on science teaching and learning as a political act. It prompted us to consider how sustainability is interpreted and enacted at the local level and challenged us to re-think sustainability in light of new questions, contexts and modes of research that might emerge in a post-Anthropocene world.

Designing learning ecologies for sustainability and critical response-ability

In the examples provided above, Black, Brown and Latinx youth occupy positions of critical research partners, owners and authors, whose existing knowledge, skills, cultures, and identities are central to their learning. These positionings, including rights and duties for self-determination, self-expression, and self-authorship, afford youth to not only take charge of their own learning, but also develop collective transformative power in relation to changing normative science identities and spaces. When youth are positioned as critical and powerful partners, this, in essence, shifts our understanding of empowerment to critical response-ability in ways that enable youth and their voices to be recognized as critical in reimagining and redefining what it means to do science and create sustainable futures. From this perspective, agency and power are not necessarily located solely within individuals, but rather in relational accountability with interactions, relations, and collectives of humans and more-than-humans. It is not that some have agency or others lack agency;

rather, agency is understood as distributed, emergent, and relational. In this sense critical response-ability is attuned to justice, on radical interdependence, autonomy, interconnections of human and more-than-human encounters, relations, politics, narratives, and practices (Escobar, 2018). In the following section, we provide brief descriptions of some of the key elements of designing learning ecologies for sustainability and critical response-ability that emerged through the process of doing this work. We consider these elements critical to designing learning ecologies for sustainability and justice.

Eradicating the processes of marginalization of diverse ways of knowing and being/becoming: identification over access.

In the process of co-constructing learning ecologies focusing on critical response-ability, we recognize that there might be a tension between teachers wanting to center students' identities, culture, and knowledge, and the desire to uphold dominant ways of knowing and being. These dominant perspectives have become so "natural" that there might be a temptation to perpetuate normative images of what constitutes "good" science students or what we perceive to be a good science engagement, instead of creating spaces, locations of possibilities, for young people to show who they are as science people in their own ways and rights (Kayumova & Harper, 2020). Young people are very smart, smarter than perhaps many adults. They can pick up or learn more than the content (e.g., science). More than often, interactions within learning ecologies can tacitly reinforce hierarchical relations to existing knowledge systems, rules, norms, and identities (Adams, Gupta, & DeFelice, 2012). This includes how diverse young people's social identities are positioned and expected to change in relation to dominant culture and practices, and how these expectations come from a position of power. From the perspective of critical response-ability, young people must be positioned as rightful owners and authors of learning spaces (Kayumova, McGuire, & Cardello, 2019). Beyond access to spaces, tools, and resources, there must be interactional and relationally just opportunities for young people to cultivate and celebrate their multiple social identities, including their social, cultural and linguistic backgrounds. Rather than asking them to be "someone" new or asking them to leave a part of their identities at the door, whether it is their language, culture, or social selves, transformative spaces and locations of possibility honor and cultivate diverse ways of being and knowing. As a result, it is not only young people, and their relations toward what it means to do science that changes, but also, and most importantly, it is otherwise marginalizing science spaces that are changing.

Examining power and politics in science and its implications for a sustainable present and futures

When it comes to designing learning ecologies for sustainable, just, and thriving present and futures, it is important to create critical spaces for complexity and systems thinking. As exemplified in our examples, current efforts to encourage systems thinking often fall short when it comes to exploring how social and political systems interact with ecological dimensions of planetary systems. Thus, it is important to foster opportunities for students to examine issues of power and politics as they engage in complexity and systems thinking. For instance, although science is often taught and presented as a neutral and objective process, emphasizing rational and evidence-based decision making, it can also be highly politicized. The current events related to climate crisis, the COVID-19 pandemic, and

issues related to systemic racism have revealed the "contingent and negotiated character of scientific knowledge" (Jasanoff, 1990, p. 2). Critical systems thinking can allow young people to engage with these complexities and entangled nature of science and politics, in the context of natural and social relations. Examination of these issues may help young people to envision a better and more ethical and "humanized" science (Gutiérrez, 2018), rather than leaving them with the impression that science is either systematically manipulated or distorted, or that it is not real, further perpetuating scientific skepticism and deference (Jasanoff, 1990). A case in point is the role that predictive modeling has and continues to play in forecasting the spread of the COVID-19 virus and understanding its natural progression. Scientists rely on scientific models and mathematical algorithms to produce models and simulations. Modeling is also an important skill and concept taught in school science. By extension teachers are expected to make these skills and concepts relevant and meaningful for students, so that they can not only make sense of science, but also appreciate the ways in which it plays a role in our daily lives. Yet modeling is often taught through far-off or artificial examples as a static body of knowledge. It is often the case that models are presented as ready-made facts; however, modeling is a complex process contingent on the kind of data and parameters used. Developing an understanding of the phenomenon of emergence or modeling of complex systems is not an easy task, just like we are witnessing in the case of the COVID-19 pandemic. In the case of COVID-19, the virus requires a host to survive and spread, and we need to understand human and other than human interactions to evaluate the nature and the degree of the spread to be able to develop models. So, the emergence and the spread of the COVID-19 pandemic relies on the interaction of biological, natural, and environmental (including human, social, and cultural) systems, as well as political decisions and regulations. This is coupled with political and socioeconomic contentions, as well as issues related to the public distrust of science. At a relatively micro-level, where do we learn about viruses (micro-organisms), spread of the disease, exponential growth, emergent phenomena, or how models and scientific modeling works? All of these cross-cutting concepts, disciplinary core ideas, and science practices are central to the vision of science teaching and learning put forth by the Next Generation Science Standards (NGSS) (National Research Council, 2013). So where is the disconnect and why has science education been proven to be so impotent (e.g., from existing inequities to public distrust)?

Partly, we argue that many of these topics and concepts are presented in isolation, as if they stand apart neutrally and naturally, rather than being embedded and entangled within complex human, natural, social-political and historical interactions and systems. The point is that the ways in which we have been teaching science as neutral, universal, disembodied, apolitical and ahistorical not only disservices young people, but also science itself. Instead of science related issues and knowledges being presented to students as abstract and ready-made "natural" facts (Kelly & Chen, 1999), a critical response-ability framework puts the rights and the voices of local communities at the forefront and seeks to eliminate the false image of both science from scientists and natural from social/cultural as if they are separate and "sterile" entities independent of each other. This false image often permeates current science curricula and becomes consequential in maintaining binary assumptions about nature-culture relations (Hufnagel et al., 2018). Attending to issues of power and politics and showing how science and scientific work can become implicated in the political and social-economic decisions made on behalf of communities is another important way of showing the centrality of science in young peoples' lives. Thus, instead of perpetuating an "idealized picture of science," we need to develop a more holistic picture of the discipline, in ways that foster a shared understanding of how participating in scientific knowledge

production and decision-making has greater implications for the present and future of our communities in building socially, environmentally and culturally sustaining and thriving communities.

Attending to epistemic and cultural heterogeneity and boundary work

From the perspective of critical-response-ability, creating locations of possibility for transformative learning ecologies also must take into account issues related to cognitive authority and boundary work. Attending to and examining sociopolitical dimensions of participating in science, Sheila Jasanoff (1990) argues, building on the work of Thomas Gieryn, that one of the ways in which scientists have preserved their cognitive authority is by "boundary work" (p. 14). As Jasanoff describes:

> Whether they are engaged in building professional communities, defining and excluding nonmembers, competing for resources, or asserting their autonomy against external controls, scientists use a variety of boundary-defining strategies to establish who is in and who is out of relevant peer groups and networks of prestige and authority…When an area of intellectual activity is tagged with the label of "science," people who are not scientists are de facto barred from having any say about its substance; correspondingly, to label something "not science is to denude it of cognitive authority." (p. 14)

The concept of "boundary work" has a direct link to what we understand as happening overall in science education and learning, with implications for broadening participation in science, as well as considering whose perspectives, voices, onto-epistemologies and ethical positions are included and excluded. Historically, the development of Western scientific and technological knowledge also resulted in the erasure of onto-epistemologies and axiologies that were not situated in European and masculine perspectives to the detriment of actual overall progress for all (Wynter, 2015). The medical knowledge of women in the early modern period was systematically wiped out with witch trials, as was the medical knowledge of the Americas as the indigenous populations and cultures were nearly decimated by the disease and genocide that accompanied colonialism and settler-colonialism. Blacks were dehumanized and objectified through slavery and the promotion of white supremacy ideologies. A form of boundary-work is also documented in the decades old studies in learning sciences (Sengupta, 2020) which demonstrate that young people and adults from various Indigenous cultures engage in scientific sense-making using cultural, heterogenous, and spiritual ways of knowing, being/becoming, and relating to the world that have not been deemed legitimate or valued in science education (Rosebery, Ogonowski, DiSchino & Warren, 2010). When cultural and onto-epistemic heterogeneity is not cultivated and celebrated within the curriculum and at the schooling level from K-16, then many of these practices are not only stripped of their cognitive authority, but also intergenerational and ancestral systems of knowledge become subject to predation (Mignolo, 2015). This is particularly salient to discourses surrounding the Anthropocene where, as described by Fikile Nxumalo (2020), the engagements remain,

> overwhelmingly white and Eurocentric, largely ignoring the fact that while "we are in this environmental mess together," there is no universal "we" in relation to who counts as fully human, who currently suffers and will suffer the most, whose knowledges count the most, what ways of relating to and responding to living-with the

Anthropocene are made visible, and in who gets to learn in complex and situated ways with and about the environment (p. 567).

To date, the conditions created by "boundary work" result in marginalization of Black, Brown, Latinx, and Indigenous voices and their presence in science disciplines. This perpetuates social, economic, health, and environmental injustices in marginalized and non-dominant communities, while simultaneously constraining their ability to become involved in critical issues directly implicating their work, environment, health, socio-cultural, economic and political conditions.

As Basile and Murray (2015) argue:

> Especially in our segregated society, it can be difficult for a collective of white middle-class scientists to understand the lives, experiences, needs, and desires of peoples of color … that this inability to see might in turn lead to scientific knowledge or applications of that scientific knowledge that are unjust … when we do not include diverse voices in the project of generating scientific knowledge and deciding how we ought to put that knowledge to use in our society. It is difficult to imagine, for example, that low-income and Latino communities of central and southern California, plagued by birth defects, would be home to the only toxic waste sites in the state … if scientists originating from those communities were involved in the scientific community. (p. 257).

In the examples we described earlier, we attended to the issues of boundary work by explicitly recognizing young people and community members as equal and knowledgeable partners. Through the lens of critical response-ability, we explicitly focused on interactional and relational dynamics of the learning space in an effort to blur traditional boundaries and hierarchies such as expert-novice, teacher-student, and adult–child (Vossoughi et al., 2020). The argument is that while broadening participation, access, and opportunity to participate in robust science learning spaces is certainly important, participation by itself may not be enough to eliminate cultural, epistemic, and systemic issues of domination and marginalization. If we fail to examine issues of power and privilege embedded in the design of learning ecologies, then patterns of inequitable participation and "boundary work" will continue to exist.

As we move forward: advancing a vision of sustainable science education

Transforming science spaces and designing for sustainable and just worlds requires attending and committing to bringing, diverse voices and presence of Black, Brown, Latinx and Indigenous communities and onto-epistemic heterogeneity and pluralism into science and our conceptions of sustainable living. In short, it is not enough to say that diverse voices matter—we must actively practice transformation by making sure that STEM spaces are occupied/transformed by diverse multilingual youth and diverse voices. When young people co-participate in the research and critical design processes and share their thinking and knowledge in public spheres, they tap into systems of existing intergenerational knowledges and bridge perceived binaries between institutional and everyday knowledge. These design partnerships have potential to bring forth the importance of care, mutual well-being,

(Tobin, 2018) respect, trust, and relationality that could be at the heart of designing for sustainable, thriving, pluralistic, and ecologically just societies.

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