



Just worlding design principles: childrens' multispecies and radical care priorities in science and engineering education

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Abstract

Due to the influence of the Next Generation Science Standards (NGSS), the National Research Council's (NRC) *Framework for K-12 Science Education*, and a socio-workforce push to increase diverse representation in STEM fields, engineering education has become more prevalent in K-12 classrooms over the past decade. Although this shift is seemingly optimistic, critical consideration must be given to the ways engineering education tends to be reductive and positivistic, mimicking engineering practices decontextualized from high-stakes socio-political and socio-ecological realities through the adherence of a closed, systematic design process. Teaching and learning that is situated within the confines of normative engineering learning fail to nurture and cultivate students' intellectual health and ontological security, and further promotes destructive settler ecologics. This study took up efforts to disrupt and desettle engineering education, which opened space for children to critically speculate about real-world engineering entanglements deeply connected to their futurities. The aims of this paper are to (1) establish the need for anticolonial engineering, and engineering education, (2) promote approaches for doing so (3) and elevate the just worlding engineering design principles put forward by radically caring children committed to socio-ecological and multispecies justice. The learning shared in this paper suggests not only why science and engineering fields and education should be reformed, but also provides guidance for evolving the designing of shared worlds, for kincentric flourishing.

Keywords Science education · Engineering · Decolonization · Early childhood education · Multispecies justice

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Sadly, children's passion for thinking often ends when they encounter a world that seeks to educate them for conformity and obedience only. (bell hooks 2013, p. 13)

As a multigenerational collective of Earthly beings and entities, coexisting across spatial temporalities and geographies, we are witnessing and striving to endure the realities and ongoing fallout of global pandemics, climate catastrophe, socio-political upheaval, and reckonings. Confrontation and conflict between opposing ideologies of settler colonialism and anti-coloniality, white supremacy and antiracism, challenge the very ways we live with one another, and live upon, with, and from the Earth. Despite claims of neutrality and objectivity, the field of engineering and the education of engineering, quite literally by design, have uniquely contributed to our current convergence of multiple crises and injustice by fortifying and reproducing oppressive power hierarchies and settler ecologies. The culpability of and urgency for change in engineering education is reflected in Lionel Claris and Donna Riley's 2012 article, "Situation critical: Critical theory and critical thinking in engineering education."

We long ago reached a certain 'situation critical' in engineering, in which engineers may have abundant logical thinking skills but no practice of thinking critically about problem framing, power relations within the profession, hegemonic epistemologies of the discipline, or reproductive practices of engineering education. This leaves society with technologies that replicate power relations of the status quo, and the profession with intractable problems around underrepresentation of white women and women and men of color, and few tools for understanding or talking about these problems, let alone acting effectively for change. (2012, p. 102)

This calling out of a "situation critical" and calling in for change within science and engineering was made a decade ago, and yet, concerns about engineering education and its outcomes have only grown in complexity and criticality. Critiques of the long-standing and current instructional approaches and standards elevate the opportunity to evolve engineering as more than a technocratic endeavor, but as a discipline that can solve global and local problems with consideration of multiple perspectives, social responsibility and dimensions of care (Gunckel and Tolbert 2018). The application of an ethical stance of radical care within the disciplines of science and engineering requires an eyes-wide-open, caring of neglected things in an aching world (Puig de la Bellacasa 2011). Such a worthy endeavor would require a transformation of engineering purposes and the education of engineers. While recent and promising critical approaches to engineering education (McGowan and Bell 2020) and matters of care in science and technology studies (Puig de la Bellacasa 2011; Puig de la Bellacasa 2017) provide theoretical grounds for destabilizing engineering and education research, approaches that foreground and prioritize the radical caring of multispecies and LandAirWaterStars have yet to be translated to engineering educational standards and design priorities. (*I use the term "LandAirWaterStars" to attend to the problematic ways that dominant, Westernized culture collapses Lands, Air, Waterways, Animals, Plants, Stars and Soil into terms such as "nature" or "environment," in effort to honor each entity and connection. The capitalization is done with intention.*)

By recognizing the lack of care and critical considerations in existing science and engineering education, we can trace these problematic deficiencies to the pervasive influence of settler colonialism. Settler colonialism suppresses care in science and engineering, stemming from progress narratives fueled and dependent on the consumption of and extraction from LandAirWaterStars, while simultaneously causing the erasure and exploitation of Indigenous, Black, and Brown minds, bodies, and lives. By identifying settler ecologies as

they are implicitly and explicitly reified epistemologically and ontologically within science and engineering, this study aimed to further efforts to desettle (Bang 2012) rather than decolonize (Sailiata 2015), learning spaces for ecological, socio-spatial and multispecies justice through approaches of radical care asserted by youth.

Furthermore, despite efforts to increase student voice in STEM classrooms, curricular and pedagogical changes far too often feign the centering of students' epistemic agency, "while actually positioning students as receivers of 'correct' information and practices" (Miller, Manz, Russ, Stroupe and Berland 2018, p. 1056) thereby maintaining hierarchical binaries of adult educator and child learner (Vossoughi, Davis, Jackson, Echevarria, Muñoz and Escudé 2021) and status quo affirming epistemologies. This study sought to challenge these realities by mapping youths' ontologies and epistemologies onto science and engineering learning, teaching and doing while engaging educators with youth—not positioning youth as heroes, but as guides, and visionaries that have sight that has yet to be fully impacted by the cataracts of living within the machinery of capitalism and settler colonialism. By examining students' ways of understanding engineering as deeply connected to the care of disenfranchised communities, multispecies and LandAirWaterStars, this study was able to capture students' radical ways of caring in engineering that exceed the parameters of mainstream implementation of science educational and standards, curricular and instructional reform, and moreover provide a trajectory for how to desettle the field of science and engineering education toward just worlding and kincentric flourishing. This design-based research pursues these related research questions:

1. When situated in learning spaces of desettled engineering education, how do students engage in the co-construction of epistemic agency to promote their ontological security and perspectives on worlding just worlds?
2. What engineering design priorities do students provide the field of engineering education and engineers, for considering Multispecies, LandAirWaterStars, community and global futurities?

Theoretical frameworks

Attending to and disrupting settler ecologics

Leaning on and leveraging Indigenous scholars and scholarship on settler colonialism and settler ecologics, I seek to call out how westernized science and engineering education secure settler futurities and continue invasion, elimination and mobility through deceiving progress narratives which indoctrinate learners—learners who become scientists, engineers, educators and citizens. In Rene Dietrich's article, "Made to Move, Made of this Place: *Into America*, Mobility, and the ecologics of Settler Colonialism," he defines settler ego-logics as, "an underlying set of logics through which settler colonial projects produce ecological disruption" through the "regularly unmarked and naturalized logics of exploitation, extraction, and profit maximization operative in settler-nation states" (2016, p. 510). Through acts of invasion, elimination, and mobility, settler ecologics design develop and materialize structural trophies and mechanizations of settler industrial progress and capitalist modernity (Tuck and Recollet 2016). Settler invasion consumes and (re)stories Indigenous ecological expertise and existence through processes of exploitation and extraction of Native peoples, species, and lands—all of which, through settler ecologics, are determined to be

inevitable, justifiable collateral costs of innovation and progress (Wolfe 2006). The insatiable appetite of the settler ecologies of mobility—the “moving in, extracting, and moving on” (Dietrich 2016, p. 510), along every frontier—devastates and reshapes the land, forces dispossession and instills narratives of the disposability of multispecies kin and non-settler communities, thereby securing the futurity of settler colonialism and capitalism.

Due to the violent misalignment with laws of nature and care for all beings, the persistence and pervasiveness of settler ecologies requires the ongoing maintenance of structures and systems of white epistemic and axiological supremacy, which further the elimination and replacement of holistic and Indigenous ways of knowing and being. Within science and engineering, settler ecologies are more than maintained—they thrive. They thrive within engineering design process models, blueprints, cost analyses, and standards and are entrenched in the mindscapes of scientists, engineers, and educators. As an opening for disrupting, dismantling, and unsettling settler ecologies, this paper is an invitation to respectfully consider the mapping of our own colonial minds.

On a personal note, I share a story to ground this invitation for future naming and noticing of settler colonialism’s invasion of our psyches and thus our practices, epistemologies, and ontologies. During a spring morning, I was sharing a quiet moment outside with my youngest son. As I sipped my cafecito, he softly whispered to me, “Mom, shh, the bunnies are back.” The fact that he knew of the bunnies, and that we even had bunnies, was new to me. After some time of stillness, the bunnies left from our view and I asked my son, “Are you going to name the bunnies?” Without hesitation or emphasis, he simply said, “Mom, what makes you think they wouldn’t already have names?”.

Although seemingly brief, for me, this was a moment of deep awareness, awareness that despite actively working to desettle science education, settler colonialism is ingrained within me. I had assumed inferiority of the bunnies, considered them to be absent without my presence, and tried to use naming and labeling as acts of possession and storying into my existence—all linkages toward the colonial logic of human supremacy. I offer this story as a humble exemplar of two points of thought: First, to illustrate my son’s knowing located within a pre-colonial mindset (Watts 2013) and, second, to share my own as a mindset that strives to be desettled but bears the marks of colonial programming. The intention is also to situate youth within this paper as guides, as intellectuals, but not in the problematic ways that romanticize youth as they connect with, care for and theorize about nature. The aim of this study is to elevate and be in solidarity with scholars such as Affrica Taylor, who challenge the colonial assertion that “there is a paradoxical assumption that children and nature belong together, as sites of innocence and purity, not as always-already entangled and unevenly co-constituted participants in world-making” (Nxumalo and Cedillo 2017, p.101). Recognizing youth as experts in and guides for world-making requires shifting theories of children with/in nature and disrupting adult/child/nature hierarchies in order to recognize the agency of youth, multispecies and LandAirWaterStars as essential to creating connections needed for attending to broken-built worlds (Nxumalo 2018). Such a paradigm shift starves the roots of ongoing coloniality by refusing the ideas that youth are naive, less-than adults, and lacking the power and agency earned by the letting go of childish ways of knowing and caring, replaced by colonial thought and narratives needed to participate in colonial systems of white supremacy. Within the story I shared, as a product of and actor of settler colonialism, my question about naming the bunnies reflects the acquisition and denial of agency of more-than human other, rather than honoring and recognizing the relational agency myself, my son, and the bunny have merely by holding place and consciousness together. My son matter-of-factly knows that his world is

inclusive of the worlds made by the bunnies, the bees that visit, the dandelions he says are pretty, the crows that feed on the grubs, these worlds within worlds, all connected, with valid doing, being and happenings, despite/in spite of human-centric enactments and ideologies.

Original intuition, emplaced agency, and children

If we hold the understanding my son illuminated as truth, then we begin to grapple with the idea that agency is not something given from above, within a hierarchy of power and domination, but rather exists within the matter and mattering of all humans and more-than humans. Vanessa Watts (2013) offers the theory of place-thought, which takes the ontological–epistemological stance that there is a “non-distinctive space where place and thought were never separated because they never could or can be separated” (p. 21). With roots in Anishinaabe and Haudenosaunee cosmologies, place-thought theory is based upon the fact that “land is alive and thinking and that humans and non-humans derive agency through the extensions of these thoughts” (p. 21) and the stance that “if we think of agency as being tied to spirit, and spirit exists in all things, then all things possess agency” (p. 30).

The concept that Plants, Animals, Lands, Air, Waters, and Stars have agency because they simply exist, separate and in relation to one another, not based on what humans determine them to be, is absent in westernized science and engineering. Settler colonial instructions for managing more-than humans require erasing their agency, extracting their mattering, and experiences in order to subjugate them to the will and agendas of humans and human industrial progress. Settler colonial thought strips away relational complexities in order to reduce knowledge into binaries like nature/culture, good/bad, living/non-living, and civilized/wild. This reductive approach provides a scaffold for domination, profit, and operationalizing settler ecologics. As Bang (2017) writes, “Settler-colonialism minimizes the importance of the natural world, and constructs narrow relations between humans and the natural world. Nature’s ontological status is relegated to that of a resource” (p.132). Without relational complexities, knowledge and knowing of self and others are incomplete, inefficient, short-sighted and devastating. Liberatory transformation of science and engineering demands the (un)learning of settler colonialism, which can begin with the understanding that it is a construct that can be undone. It has an origin of place in our minds that informs practice. According to Tiokasin Ghosthorse, returning to our original instructions means a returning to original intuition, which means a returning to our relations and a returning to listening to Earth, knowing she is listening to us, and knowing science is within and because of nature (Young 2021). Original instructions/original intuition, according to Vanessa Watts, lives within the “pre-colonial mind” (2013, p. 22) accessed by reaffirming the “sacred connection between place, non-human and human” (2013, p.20). Pre-colonial minds consider what the Land’s intentions might be and how she tries to speak through us and to us. For youth, like my son and the children in this study, who have yet to endure years of settler colonial programming, proximity to original intuition provides clarity of and comfort with relational complexities that holistically presence the agency and beingness of more-than humans. Before we consider the potentialities of centering youths’ logics for radical care approaches in science and engineering for worlding common worlds (Latour 2004), we need to give attention to how children are not being perceived and/or positioned in this study.

Stances on child development in this study are contrary to settler tropes of young children being developmentally inclined to have a kinship with multispecies, LandAir-WaterStars entities, and natural forces as evidence of naivete—as a beginning stage of human development, not yet complete. This research challenges the perception that humans become more whole as they move away from so-called innocence, along developmental trajectory toward adulthood, adulthood measured by achieving a nature/culture divide which further validates anthropocentric dominant ideologies and ecological harm. (Nxumalo 2015; Nxumalo 2016) Instead, this study aims to trouble such perceptions of childrens' development by elevating that this departure is anything but natural. Rather, it telegraphs the onset of settler colonial programming; it is a narration of severance from eco-social relationalities; it is cyborg-making (Haraway 1991). Centering relational pedagogies and relational onto-epistemologies of children means understanding that they are holistically, geographically, biologically, culturally, and generationally situated in multispecies entanglements, as actors and witnesses of the worlding of their always-becoming worlds (Taylor and Pacini-Ketchabaw 2018). This study aimed to design pedagogical conditions and engagements to disrupt the inscription of settler ecologics by supporting the ontological security of students' complex, original intuitions, and relational ways of knowing, considering and caring for all species and LandAirWaterStars (Bang and Marin 2015). Caring for students' ontological security requires seeing that youth are whole beings, capable of navigating complex realities and futurities and deserving of having their heterogeneity valued and presenced. To do so, particularly in formal learning spaces, means to design pedagogical practices and learning that disrupt settler colonialism conditioning through moments of critical speculation that support “students in navigating through time–space relations by creating temporal and spatial synchronicity that refused settler colonial erasure” (Bang and Marin 2015, p. 542). Countering colonial hierarchies of being and becoming requires the (re)opening of paradigms and pedagogies that not only embrace, but also honor youths' pre-colonial stances on and relationality with nature—providing adult educators and engineers with radically caring insights and sight.

Radical caring, absent from idealistic, neoliberal notions and damage-centered savior agendas, but rather is informed by critical pedagogies, provides a legitimate and liberating opportunity for the social dreaming (Espinoza 2008) of a hopeful otherwise beyond the dominant and domination of beings and worlds. As Hobart and Kneese (2020) write:

Radical care can present an otherwise, even if it cannot completely disengage from structural inequalities and normative assumptions regarding social reproduction, gender, race, class, sexuality, and citizenship (p.3) “...care is about the survival of marginal communities because it is intimately connected to modern radical politics and activism....During moments of crisis, radical care allows communities to live through hardship” (p. 10).

Aims of evolving science and engineering to have a pulse, a heartbeat (Frausto Aceves, Torres-Olave and Tolbert 2022) necessitates pedagogical (re)designing and (re)purposing to center youth knowledges and radical care while supporting youth as they learn about and speculate about the world and the world that is yet to be.

Methods

Curricular design implementation

Engaging students in critical speculation at the boundaries of settled, Anglo-western, science provides escape routes, pathways, and expansive learning landscapes. It presents ontological intuitions, epistemic awarenesses, and socio-ecological complexities so youth agentically engage in worlding practices for social change. In consideration of the urgent need to desettle science and engineering that reifies settler colonial ecologics, this study leveraged the Critical Speculative Design Pedagogy framework (Arada, Sanchez and Bell 2023) to move teaching and learning outside the enclosures of normative engineering pedagogies and processes.

Critical Speculative Design Pedagogy Framework (CSDP) aims to attend to the call for socio-political, socio-ecologically conscious teaching and learning that focalizes and vocalizes *the how*, *the for what*, *the for whom*, and *the with whom* of teaching and learning (Philip, Bang and Jackson 2018) and be mindful of how understandings of the past and present inform the designing and building of worlds in which youth are critically enmeshed. Thus, the CSDP framework is grounded in the recognition that youth have the epistemic right to engage in learning that honors and centers their ontological orientations, knowledges and ways of knowing within consequential, future-facing endeavors. Within CSDP, youth are valued as generational stakeholders who can and necessarily are positioned to speculate about a best ways forward to design for just worlds, despite and in spite of unjust complexities and socio-ecological doings and undoings. CSDP framework includes instructional design elements of *constellar youth knowledges*, *consequential concern*, *critical liberatory presencing*, *futurity play* and *kindred relationality*. These design elements are not to be understood as separate but as interwoven, as they form the connective heart tissue of radical care desperately needed in an engineering and engineering education centered on social and multispecies justice (Arada, Sanchez and Bell 2023).

Implementation of the CSDP framework in the curricular design of this study foregrounded students' constellar knowledges, not merely as moves toward inclusion for assimilative participation, but for visibilizing the onto-epistemic heterogeneity missing in reductive, zero-sum learning (Warren, Vossoughi, Rosebery, Bang and Taylor 2020). Designing curricular learning that prioritize the presence and weaving students' generational and relational constellar knowledges disrupts epistemic arrogance and hierarchy espoused in dominate science and engineering education. This foregrounding carves out pedagogical possibilities for epistemic desettling that produce expansive learning landscapes for community and global mattering(s) that are beautiful, troubling and yet to be dreamt. Within engineering education, the CSDP framework approach illuminates the ways engineering design and content are situated in real-world contexts with consequential generational and socio-ecological concerns. By grounding engineering learning in consequential concerns, students' critical sociotechnical literacy is nurtured as they "think about the social implications of their designs and their impact on the social structures and sustainability of communities" (McGowan and Bell 2020, p. 15). The CSDP framework pushes on ambiguous undertakings and understandings of "sustainability" and encourages communities to leverage a critical liberatory presencing (Sanchez, in press) which calls for the dignity-affirming and generative representation of Black, Brown, and Indigenous brilliance, experiences, and futurisms (Espinosa and Vossoughi 2014). This necessitates shifting engineering, and engineering education, away from technocratic problem-solving and product-development

agendas, toward engineering that prioritizes boundless speculative thought and consideration of and for kincentric flourishing (of community, multispecies, and LandAirWater-Stars). These expansive priorities, as they are taken up in CSDP, negate moves toward eco-apocalyptic, universalist stances that by default secure only white futurites. Rather, these priorities aim to engage in the cultivation of what Mitchell and Chaudhury (2020) call *plural imaginaries*, that “exceed white visions of ‘the’ end of ‘the world’, embodying much wider, diverse, and transformative concepts of, and beyond, ‘humanity’, ‘nature’, and ‘the planet’” (p. 2). Engineering education that positions learners as co-designers with shared responsibility to (re)design just worlds of reciprocity and relationality necessarily requires critical speculation beyond the confines of settler colonial and neoliberal logics of progress and technocratic innovation.

Learning context

This study is part of a longitudinal, multi-scale research practice partnership (RPP) between the University of Washington and a local school district. In effort to attend to a leading edge of science and engineering education research, a cohort of teachers participated in a kindergarten-through-sixth grade pilot of the Social Focus Initiative. Guided by the Social Focus framework (Sanchez, in press), the Social Focus Initiative began in local middle schools, aimed to support the teacher learning and development of justice-oriented, culturally resurgent science instruction. For this study, two white teachers from different schools opted to pilot a Social Focus third-grade science and engineering unit in collaboration with myself and my graduate researcher partner, Kelsie Fowler. The partnership employed a social design research approach, which positions teachers and researchers as collaborators in the pursuit of transforming science and engineering education. Between the two teachers, there were three classes totaling 64 students, with one of the teachers having two science classes. The two schools shared similar student demographics, and in aggregate across both schools, 55% of students identified as being part of racial and/or cultural groups representing people of the global majority, with the remaining 45% of students identifying as white.

It is important to note that the research conducted in this study was done during the height of the COVID-19 global pandemic, which abruptly moved public school learning from the classroom into the homes of teachers and students. Given these unprecedented conditions, teachers, students, and families traversed along a steep learning curve of digital remote instruction. Necessarily, teachers and researchers adapted to these new conditions, editing lessons for compatibility with online learning platforms. Therefore, data collection for this study was done remotely. Due to mandates enforced by the district, science instruction time was reduced, impacting the scale of the research and partnership. Importantly, these unforeseen complexities and constraints are not shared to paint a scenario of limitation, but rather to highlight that the children in this study embraced the expansiveness of the new curriculum despite such conditions, brilliantly offering up kincentric engineering design principles to move the field of engineering toward just worlding.

Curriculum enactment and data collection

Selection of the third-grade physics and engineering unit was based on previous analysis of students’ conceptual models and observational data from multiple classrooms, which revealed that students’ curiosities and speculative questions exceeded the bounds

of the adopted curriculum. This district adopted curriculum unit leveraged the phenomenon and investigation of maglev trains, which is seemingly contemporary and provocative. However, the curriculum reflected zero-point epistemological learning and storylines with ridged enclosures, which steer students toward content standards which, in this case, were myopically focused on forces of magnetism and gravity. Early analysis of students' conceptual models and classroom discourse showed that students attempted to speculate about how and where these trains existed, or if they existed at all, and if so, how they were developed, how they function beyond rising and falling, and if they are safe. Despite students' desires to learn about the sociotechnical complexities of maglev trains, the reductive curriculum and district constraints failed to attend to students' inquiries, as they were not related to the standards needed to learn to pass the end of unit assessment.

Based on this evidence, my research partner and I co-created pilot lessons using the CSDP framework to contextualize high-speed train development in real global socio-ecological spatial geographies while also providing consequential learning opportunities to nurture students' intellectual health. To support youth intellectual health, we engaged them in the "intellectual work of storying" and "dreaming forward" about "healthful ways to think about the world and to deliberate about the world, to think about what could be, to think about the challenges of living in Westernized systems things like decolonization, things like understanding colonial systems but also things like how do we generate a new always" (Bang 2020, 20:14–20:36). Developing pilot science and engineering lessons to nurture students' intellectual health required shared understanding among the design team that youth are already positioned within power-laden socio-ecological entanglements that are ever-present in sociotechnical developments. Therefore, youth were provided opportunities to critically speculate and get into the muck that is at the intersection of technoscientific development with cultural, multispecies and ecological realities and futures.

The unit created for this study aimed to engage third-grade children in speculation and deliberation about science and engineering innovation, centering learning around the Social Focus question *What and who should scientists and engineers consider when developing technology and solutions?* The arc of learning began with a family and community elicitation about the role and experiences with transportation and speculative designs of possible future forms of high-speed transportation. This type of elicitation moves away from performative and interloper lessons that ask students' families to share how the content resonates with their lives, never to be revisited. Instead, the elicitation was designed as a self-documenting activity to presence the expertise within students' worlds and communities, to inform how content is considered and move learning outside the barriers of settled learning (Tzou and Bell 2010). Following the elicitation, perspective-taking lessons and materials were created to continue to move content and learning to challenging positivistic, technocratic engineering stances to shift learning toward learners' kincentric orientations and intuitions.

Grounded in posthumanist feminist science theory, perspective-taking learning activities, called *stakeholder lessons*, push for the critical liberatory presencing of the oppressed and invisible human and more-than-human actors (Medin and Bang 2014). The pedagogical practice of perspective-taking positions learners to traverse spatial and temporal boundaries and engage relational epistemologies to connect content to complex roles within socio-ecological systems and places (Pugh, McGinty and Bang 2019). For this study, perspective-taking began within student-led discussions, which asked them to consider who is an engineer and where engineering is done, moving perspectives away from white identities and countries as dominant doers of engineering. Students then learned that high-speed

trains are a global endeavor by conducting critical research activities on four real-world high-speed trains currently in stages of development or proposed for development. Discourse prompts and activities were embedded to help students deliberate as peers about why the trains were being proposed or developed, consequential concerns about development, and who and what should be considered when making final decisions about the trains.

These critical research perspective-taking activities were created to help students consider the complexities of building the train, including the impacts to local communities and impacts to natural environments. The unit culminated with students taking the perspective of engineering design team members tasked to invite the stakeholders they considered to be essential to determine how and if the train would be built. (See Appendix for detail.)

Qualitative analytical methods

To address the proposed research questions, I employed a thematic analysis approach (Braun and Clark 2017). Thankfully, I was able to attend the majority of all the science classes in this study as an insider participant, therefore I took ethnographic notes while reviewing the class recordings, documenting the interactions between students and teachers and peer discourse in the whole group space, break-out rooms and within the online chat space. This approach and process was emulated by my co-researcher Kelsie Fowler, which informed our conversations, guided by a grounded theory approach that asks, “What is happening here?” (Charmaz 2001, p. 337).

Through the analysis of notes, classroom video and student artifacts, with critical attention to how students engaged in the threading and weaving of science and engineering content and their constellar knowledges and perspectives on multispecies and LandAirWaterStars, patterns of socio-ecological care in engineering became evident. These patterns materialized succinctly in students’ culminating assignment of Stakeholder Design Meeting Invitations, making these artifacts the primary data set and unit of analysis for this study. I transcribed each of the digital Stakeholder Design Meeting Invitations ($n=60$), then used a thematic analysis method (Denzin 2005) to identify salient themes within students’ responses regarding who/what they were inviting to the train design meeting. Initially using an open-coding approach (Strauss and Corbin 1998) of students’ invitations, I created categories of stakeholders, such as farmers, plants, animals, and grouped stakeholders. Then through a process of focused coding (Miles, Huberman and Saldaña 2014), these categories were organized to identify core themes in the invitations, asking the questions, *how are students positioning essential stakeholders in the design meeting and what do they elevate as vital considerations when designing and developing the maglev train?*

Findings

Are there any more human beings, seems to be there are a lot of technical humans.
— Tiokasin Ghoshorse

Promising and prescient events of anticolonial engineering education and the field of engineering are presented in the following findings. The findings are structured chronologically, narrating how the virtual classroom transformed into a space of epistemic sovereignty

for students, creating contestations of coloniality and presencing kincentric flourishing within engineering. The findings begin with how classroom learning shifted away from settled learning by asking youth to center their inter-intrapersonal connections to transportation and the engineering of future transportation. The storying of the findings then moves forward through the learning experience, sharing the ways students increasingly engaged in contestations of colonial, technocratic engineering as they learned more about the global socio-ecological context of the trains. The findings conclude with students' four critical and radically caring socio-ecological engineering design principles, which surfaced from analysis of their culminating activity.

Desettling through student inter-intrapersonal elicitations

In alignment with the CSDP framework and in effort to break through the walls of reductive science and engineering learning, an elicitation lesson was created for teachers to provide an opportunity to begin learning with the centering of students' authentic and expansive inter-intrapersonal connections to transportation and designing transportation. For this elicitation activity, students asked a family or community member(s) about what they thought about local transportation, what works, what does not work, to

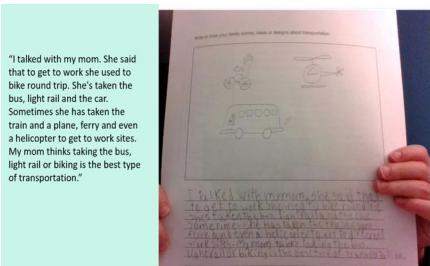
<p>1.) This student example shares a discussion they had with their mom about her experiences with transportation.</p>  <p>"I talked with my mom. She said that to get to work she needed to take round trip. She's taken the bus, light rail and the car. Sometimes she has taken the train and a plane, ferry and even a helicopter to get to work sites. My mom thinks taking the bus, light rail or biking is the best type of transportation."</p>	<p>2.) This student decided to grapple with the complexities of transportation based on their own collective understandings.</p> <table border="1"> <tr> <td data-bbox="607 908 993 996"> <p>ferries: Ferries are startle good, because you can bring your car on them, but they may have very long lines</p> </td> <td data-bbox="771 908 993 996"> <p>airplanes: Air planes are startle good, because they are very fast, and they can go over seas, but they can get you very sick.</p> </td> </tr> <tr> <td data-bbox="607 996 759 1067"> <p>light rail: The light rail is good, because it is fast. It is also bad, because it has lots of stops.</p> </td> <td data-bbox="771 996 993 1067"> <p>biking: Biking is good, because it takes no gas or fuel. They also take effort and energy</p> </td> </tr> <tr> <td colspan="2" data-bbox="607 1067 993 1094"> <p>cars: Cars are good, because they can go very fast, but they take gas.</p> </td> </tr> </table>	<p>ferries: Ferries are startle good, because you can bring your car on them, but they may have very long lines</p>	<p>airplanes: Air planes are startle good, because they are very fast, and they can go over seas, but they can get you very sick.</p>	<p>light rail: The light rail is good, because it is fast. It is also bad, because it has lots of stops.</p>	<p>biking: Biking is good, because it takes no gas or fuel. They also take effort and energy</p>	<p>cars: Cars are good, because they can go very fast, but they take gas.</p>	
<p>ferries: Ferries are startle good, because you can bring your car on them, but they may have very long lines</p>	<p>airplanes: Air planes are startle good, because they are very fast, and they can go over seas, but they can get you very sick.</p>						
<p>light rail: The light rail is good, because it is fast. It is also bad, because it has lots of stops.</p>	<p>biking: Biking is good, because it takes no gas or fuel. They also take effort and energy</p>						
<p>cars: Cars are good, because they can go very fast, but they take gas.</p>							
<p>3.) This student and their brother dreamed up a transportation device that moved people from an urban downtown immediately into a forest.</p>  <p>Justin and I came up with the idea DOWN DOWN</p>  <p>TELEPORTATION DEVICE</p>							

Fig. 1 Student transportation elicitation examples

share stories about their experiences or knowledge about various forms of transportation, and to speculate about what the perfect transportation system would look like in the future (See Fig. 1: Student elicitation examples). Community and family responses predominately focused on utility, uses, and designs of transportation, but at the same time hinged on the belief that their transportation system, as it is, is limited in its usefulness because it lacks consideration of community, the environment, and future socio-ecological needs. For example, a student's father who was video interviewed shared that there are many challenges to consider when designing local public transportation. He stated, "This is needed so bad," and at one point he says, "and here they have a lot of water to deal with and that is hard. They are building bridges because they can't just build right on or in the water....yeah, this is something they need to think about." What goes unsaid here is *why* water must be considered. However, he seeds Water, and Water-placemaking as a key stakeholder and consideration in transportation design for the future.

The elicitation activity countered dominant positivistic views of engineering and transportation that are pushed when learning is absent of personal and real-world complexities. By opening up learning to invite inter-intrapersonal connections, students and their families were elevated as valued sources of knowledge. Beginning with the inclusion of personal, complex views about the unit topic expanded learning and initiated the unit as an investment in youth's intellectual health, opening the classroom as a space to grapple with the consequential entanglements of engineering and living, lived worlds.

In class discussions about the elicitation lesson, students' inclination to *stay with the trouble* (Haraway 2016) was evident. Students weighed complexities when several students elevated the fact that not all families have access to affordable transportation, such as one student sharing that light rail "routes are probably great for families that want to go to a big soccer game but may not be close to other areas where some families need to go, to like work or see family." Class discussions toggled between the tension of naming human-centric "benefits" of transportation made by teachers such as being "fast," "efficient" and able to "go far," juxtaposed with students' holding of socio-ecological concerns, such as saying that the trains would cause "too much pollution," "we need solar panels that could be used by different forms of transportation," "for some people it might not be a good thing," "maybe there are longer lines for some people" or that the trains will be "too expensive." The elicitation and initial discourse activities illustrate youths' keen sensibilities to not just take content at face value by challenging canonical stances of technological progress. They also speak to the students' abilities, capacity and interest in taking up consequential concerns, different perspectives, and exploring the tensions and possibilities between those perspectives.

Student onto-epistemic resistance and refusals for the centering of kindred relationality

As the learning progressed, students were asked to consider research on four real-world high-speed trains being proposed for development or in stages of development in Asia. During this activity, students' inquiry into socio-geospatial realities increased, surfacing more consequential tensions about the true costs and untold truths about the trains. For example, during whole-class discussion about the pros and cons of high-speed trains, when it was mentioned that residents near the train would be able to commute to work, several

students added counter points to residents' proximity to the train as a potential cause of "noise pollution" and "litter" and inquired if the tracks would actually cause more fatalities and property damage. In one student break-out room conversation about whether or not a particular train should be built, the following was said:

Student 1: "I don't know what to think because it is a lot of money and doesn't go that much faster. [long pause] What do you think?"

Student 2: "I--I don't really know what I think because yeah it can break trees and kill animals and stuff to put it in and---and how you said Elijah, it costs 88 million dollars!!!! Like wow! But I do like that they aren't broke by earthquakes, so they won't need to be fixed and all that. Just put in. But yeah, I don't really know."

The above student conversation excerpt is representative of how the third-grade students in this study embraced the troubling of the development of the four trains they researched. Designing science and engineering education that prioritizes consistent, expansive, critical, and speculative learning opportunities (re)opens up the classroom as a space that contradicts learning that attempts to espouse "one right answer" white supremacy traits (Jones and Okun 2001), which fails to nurture students' intellectual health.

The next lesson in the sequence of critical research learning shifted from having students investigate four trains to focusing specifically on one high-speed train being proposed for development in South Korea. Although *either/or thinking* is a trait of dominant white supremacy culture (Jones and Okun 2001), binary instruction and instructional practices, such as pro/cons lists, continued to be employed by teachers. However, students resisted this simplistic mindset, opting for more rigorous thinking and questioning if there could truly be pros with so much harm to nature and communities. Students were attuned to settler colonial default thinking, which considers increased tourism and economic growth as uncomplicated pros and collapses cons into "impacts to nature," invisibilizing LandAirWaterStars, multispecies animals and plants and oppressed human community members.

The more the teachers tried to "see both sides" (teacher quote during a post-observation conversation), the more the students engaged in acts of contestation and critical inquiry, which ignited a culture of collective refusal and reclamation of the learning space. Evidence of this shift arose in the way students began to take ownership of the online chat space to present their onto-epistemic refusals. Knowing that the teacher did

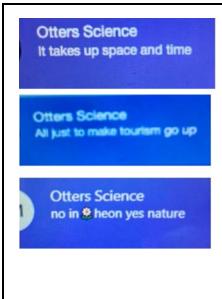
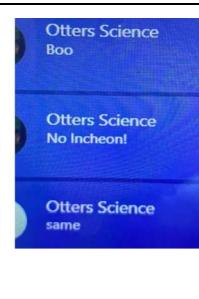
		<p>Student chat regarding the train being developed in Incheon, South Korea:</p> <p>S1: "It takes up space and time." S2: "All just to make tourism go up?" S3: "no in cheon yes nature" S4: "Boo" and "No Incheon" S5: "same"</p>
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Fig. 2 Example of chat contestations as acts of refusal

not often monitor the online chat space, students engaged in rogue side conversations pushing back on narratives about the train being a technological innovation engineers had created for human progress. In several instances, students even resisted releasing the chat space after class ended by continuing peer discussions after class in a way that refuted the in-class conversation (see Fig. 2).

Following the lessons that engaged students in learning and wrestling with background research on the focal train, students engaged in a set of stakeholder lessons. The design of stakeholder lessons call for the critical liberatory presencing (Sanchez, in press) of beings and natural entities that all would otherwise be marginalized in normative science and engineering education. The stakeholder lessons also intended to promote perspective-taking to answer the unit Social Focus question, *What and who should scientists and engineers consider when developing technology and solutions?* While stakeholder lessons were intended to surface this question, the students were already far ahead of the designed curriculum, considering perspectives and beings absent from the conversation from the very beginning.

As learning unfolded, students' resistance and refusals and moves to (re)story the engineering storyline further flourished when classes began identifying stakeholders. The lesson began with teachers attempting to scaffold the class discussion to create another binary list: stakeholders that would benefit from a train and those that would not. Students pushed back on the 'either/or thinking' list making by repositioning and reiterating relational epistemologies (Cajete 2000) as they named stakeholders. For instance, when one teacher asked, "Well, don't commuters benefit from the train?" a student responded, "People, commuters, can get to work, or where they are going fast but their neighborhood is not happy, it will be littered and have less trees." In all three classes, students made consistent moves to trouble the colonial, onto-epistemic stance of technological and economic progress, pushing back against naming stakeholders such as tourists, banks, and businesses along the train route without caring for and discussing complex relational entanglements each stakeholder posed. Eventually, this battle of wills came to an impasse, with students leveraging their power and rights of disengagement to counter the teachers' power as the instructors. If we consider the learning space to be like a property, students' disengagement in discourse reflected silent, sit-in protests which commonly occur in settler spaces as brave acts of resistance and refusal. Mirroring these acts, students, once again, turned to the chat space to voice their ideas about stakeholders and their relational reasoning for identifying stakeholders (see Fig. 3).

Students' commitment and determination to engage in relational epistemologies while considering stakeholders in the train's development resulted in teachers relinquishing the structure of the lesson by allowing students to engage in relational reasoning as they identified stakeholders. This rupture of classroom dynamics led to a profound (re)placing and (re)storying of the standardized engineering education storyline with one that embraced complex relational entanglements and socio-ecological realities, centering students' onto-epistemic knowledges and ways of knowing while also spurring teachers' critical reflection and flexion.

As a result of students' resistance and determination and the critical reflection and flexion of the teachers in the study, the stakeholder lessons were expanded to include an activity to invite stakeholders to an imagined design meeting stakeholders. The design meeting invitation lesson was created to help students continue to speculate about which essential stakeholder decision-makers would be to determine the future of the train. The outcome of the stakeholder design meeting invitation lesson expanded the engineering learning to illuminate the multispecies LandAirWaterStars kindred relationality present in all engineering endeavors.

<p>If it's gonna remove a forest, or even some part of the forest that would still be a great loss, because they make oxygen and eat carbon dioxide.</p>	<p>1:37 PM If humans also need trees and nature would they be a stakeholder? For kids that want oxygen for their lives maybe?? What do you think?</p>
<p>1:36 PM It might be VERY noisy</p>	<p>marine biologists will be sad if the waters are polluted because they study the life of marine animals and if the water is polluted they won't be able to.</p>

Fig. 3 Student discussion in online chat space

Analysis of all 64 student design meeting invitations resulted in 58% of the invitations prioritizing Animals, Land, Water and Trees as essential stakeholders. Of the remaining responses, 33% went to farmers, highlighting students' valuing of community and the relationship between farmers, Land and nearby Waters, and 9% were addressed to citizens, government officials, scientists or engineers, with invitations being framed as critiques or challenges to their presumed stance of the train development. By integrating lessons designed to value and center students' constellar knowledges and ontological security, the classroom learning space transformed. How this transformation unfolded provides insights into how students' resistance and refusals call out and call into light dominant, settled, pedagogical practices, and epistemologies, which foreclose expansive and complex future-facing thought.

Further analysis of the design meeting invitations provides researchers, educators, and the field of engineering with students' socio-ecological logics for radical caring in engineering. Students' socio-ecological logics posit a worlding (Haraway 2015) agenda and approach to engineering, shifting the purpose of design and development of human-doings and being to be in right relationship multispecies and LandAirWater-Stars kin for living reciprocally and harmoniously.

Childrens' just worlding design principles

Students' socio-ecological logics for radical care in engineering for just worlding are presented in the following section, organized by engineering principles that arose from students' stakeholder design meeting invitations.

Design Principle 1: honoring kindred relationality as design priority

Analysis of students' invitations illuminated their radical care for worlding technoscientific design as being grounded in the worlding premise that humans and more-than-human species and entities are intimately connected socio-ecologically, through time and space. For students, *knowing* of these relational entanglements seemed to be a core ontological orientation of rightful kinship, leagues away from settler processes of human supremacy. Radically caring for kinship presenced the lifeways and affective and intellectual complexities of non-human actors living alongside humans, and in consideration of humans. Naming commitments of radically caring kinship is evident in the following transcript of a student's stakeholders design meeting invitation:

[To: Landscape] I just received info that a certain train is being built around your border. I wld like you & I to meet to state your concerns and your ideas to make this train better for you and all your subjects. I will give you the intel for the ups & downs of this train. I would also like you to bring 2 or 3 of your subjects to state their concerns for other things you would like to change. Please tell us if you will be joining us, where and when. We live around the train, we don't know what to think, so you are the decider. PS: We are here for you. We are not against you, as others have been in the past.

This example of a stakeholder invitation uniquely models radically caring commitments of kinship, in that this invitation was co-authored by friends that were inspired to not only write their own invitations, but also felt moved to express their solidarity of and for kinship. These kinfolk also demonstrated their collective *knowing* of entangled and interdependent connections, while storying the complex lifeways and life-beings in a perspective-taking invitation response co-creates by three students who decided to meet over zoom to partner on an invitation response their respective stakeholders—the Landscape, Professor Owl and Elky the “scientific mind.”

[Response from Landscape, Owl & Elk] I am pleased to say that your invitation was received. I will bring my councilman, the Principal of Owlty, "if you send your kids here they won't just get a great education but they will be treated like royalty." His name is Professor (when you address him, always say professor) Owl; and my sister's.....Elky, the scientific mind of my life. Elky will represent our concerns and the public eye. Professor Owl will represent our ideas to improve and help, the world and I will represent the bond between Earth and humans.

Students' narration of Land, Owl, and Elk situates non-human animals as *embodied individuals* with a stake in the design (Houston, Hillier, MacCallum, Steele and Byrne 2018) and Land as a sentient being. This positions them not only alongside humans, but as radically caring kin committed to the cooperative nurturing and educating of “kids.”

What broken-builtness of education, engineering, and human centrism can be repaired, restored and (re)imagined if our minds and proverbial hearts are *learned up* by

the timeless knowledge(s) of LandAirWaterStars and multispecies? Puig de la Bellacasa asserts, “We must take care of things in order to remain responsible for their becomings” (2017). How does this apply to our youth? For what becomings of our youth do colonial ways of teaching and living represent tragic un-becomings? In other words, which students’ invitations present themselves at the intersection of radical and holistic becoming and un-becoming in relation to the indoctrination of colonial matrices and reconfiguring of human-LandAirWaterStars-Multispecies relations? The radical caring of kinship elevated in students’ stakeholder invitations offer insight into worlding processes that prioritize relationality, for collective continuance (Whyte 2018).

This invitation (and the other invitations) from students is not only an invitation to the Land, Owl and Elk. It is an invitation to for us as educators, as designers, as kin, to engage in *becoming worlds* that (re)storying and (re)place radically caring for multispecies and LandAirWaterStars kin at the heart of education, technoscientific design and development and within ourselves.

Design Principle 2: critical liberatory presencing of multispecies, LandAirWaterStars, and rights of nature

It has been established that the influence of settler colonialism’s epistemologies of human supremacy, which maintains nature/culture divisions, has resulted in a lack of empathy and care among technoscientific designers in the field of engineering and the education of science and engineering (Gunckel and Tolbert 2018). If we ponder the question, *At what point on the pathways of life and learning does empathy and care get replaced?*, we may find ourselves within the walls and spaces of “civilized” institutions such as school. The critical liberatory presencing of multispecies and LandAirWaterStars by students in their invitations offer a rights- and justice-forward approach toward empathetic, radically caring design and development.

In the following example, the student situates Mr. Peckie, the Woodpecker within the geography of the train, as an agentic being, reflective of place-thought, and not only capable of providing guidance to inform technoscientific designs, but also holding necessary placed and relational experiential expertise. Additionally, this example, as was true in other examples, is evident of how the content learned during the engineering critical research lessons was leveraged during the stakeholder design meeting invitations culminating lesson.

[To Mr. Peckie the Woodpecker] When we build this train we will have to cut down many trees in your habitat. We will also have to pollute wildlife water supplies in order to build the train. We have some questions for you too! First, how crucial are the trees that you live in? Second, are mountains important to your ecosystem? Third, are you okay with finding a new home? Fourth, where do you get your fresh water supply? Fifth, why did you choose to live here? Lastly, are you okay with this natural habitat being destroyed (maybe not) probably though forever?

The presencing of Mr. Peckie the Woodpecker as rights-full is evident in the fact that the line of inquiry infers that the train will destroy the Woodpecker’s habitat impacting his (gender implied by student) right to live and be in thriving relations with clean water, wildlife, mountains and trees. By understanding and elevating the inter- and intraconnect-edness of Mr. Peckie, multispecies, trees, mountains, and waters, this student materializes the embodied lifeways that will unjustly be harmed, reduced to collateral damage for colonial definitions of progress and ecologics of mobility. This student presents the rights of

the would-be-erased, displaced, unknown, and never-to-become by radically caring about the survivance and thriving of the Woodpecker's web of life. This radical care situates the design of the maglev train within the entanglement of multispecies and ecological justice and technoscientific development. Additionally, this student counters dominant humanisms in engineering through a presencing of multispecies justice and rights framing that values Mr. Peckie the Woodpecker's experience and input as central to deciding if and how the train should be developed. This student example is representative of the 58 of the 64 stakeholder design meeting invitations, which all propose the radical caring of multispecies and ecological justice by foregrounding the rights and critical liberatory presence of stakeholders for worlding just worlds. Of the six that did not directly name a multispecies and/or LandAirWaterStars stakeholder, five directly named human roles they believed to have power to make decisions about the train being developed, and one student named a Martian as a stakeholder, presencing galaxy potentialities as advance kin considerations.

Design Principle 3: transparency and humility as a valued design stance

Aligned with, and in support of the three other design principles, the call for engineering and settler transparency and humility counters anthropocentrism, which enables the fallacy that humans are the most significant entity on the planet resulting human domination-over all multispecies and LandAirWaterStars sentient entities. The following two transcripts of student design meeting invitations model engineering practices of transparency and humility to set a trajectory for just design and development while inviting methodologies of resistance and refusal.

[To: Oi River & fish] We are making a maglev train in Japan and we are building it because it will be twice as fast as the old train. We are notifying you because it may pollute the Oi river. We request that you help us create alternate tracks. We need you to come bc nobody can better help us find safe paths then somebody that lives in the Oi river and depends on it. You will give us a very new perspective because everybody else is a human. Do you already have other ideas for paths? Do you think we should cancel the whole idea? By the way, you may bring other animals and plants.

This student example models a practice of foregrounding transparency and humility in technoscientific development with the statement, "We are building it because it will be twice as fast as the old train," followed by, "We are notifying you because it may pollute the Oi river." On the surface, this would seem a simple declaration of fact. However, the student provides a model of transparency for engineering as well-naming potential socio-ecological impacts. By stating the motive for developing the train first, followed by informing the stakeholder how they may be impacted, this student radically challenges the anthropocentric dynamic of settler colonial methods of engineering. They do so first by elevating the river and fish as equal or perhaps superior beings to humans. Second, communicating and radically caring about the harm(s) caused by development is drastically counter to settler ecologies of mobility perpetuated in industrial engineering, which minimize environmental impacts and/or take a hindsight mode that sees these impacts as an inevitable and worthy cost of progress. Kristin Gunckel and Sara Tolbert call out the support for these settler ecologies of mobility and minimization of harm done to nature in the NGSS, engineering education standards and NRC Framework. They state that "by suggesting that design can solve any problem that people want to change, the *Framework* and NGSS perpetuate

the technocratic myth that societies can engineer themselves out of all complex and thorny situations without addressing the underlying human dimensions that create the problems in the first place" (2018, p. 5).

The following student stakeholder invitation shows how engineering can counter dominant and enabled stances of human exceptionalism, arrogance, and practices of deception. Leveraging their original intuition, this student provides anti-settler ecologies of transparency and humility that are visceral and palpable, using affective prose to urge rural farmers to attend the stakeholders design meeting.

[To: Farmers] We want to talk to you because we have a problem. I think you should come because you are a stakeholder and we are making an impact in your environment. The impact is that we are building a massive train. Of course before we release it we want to talk to all the stakeholders. So we really want to talk to you so we can make a decision. Now why we want you is because we want others perspectives, not just ours. We want some others' perspectives bc if we don't have other perspectives, then a lot of people will be against us. We have a few questions. That you should answer. We think we have the answer to this one but will you be fine if your crops are ruined? Probably not. Well another question is do you like noise right next to you because our train will have a lot of noise and cost a lot. Anyway that is all we wanted to ask and I hope you will share your ideas.

Humility counters westernized positivism in science and engineering which tout technoscientific innovations as universally beneficial. Humility is not synonymous with weakness, shame, or powerlessness. Rather, according to Tiokasin Ghosthorse, "We can be humbled by addressing our grief. We can be humbled by addressing that maybe we've done a little too much with technology. We made that our savior. Maybe we've done a lot of things that we should have never done" (Young 2021, 57:30). Students' narratives of humility restructure power by positioning community and ecological entities as resources of expert and necessary knowledge. In the example of the Oi river and fish, when the student writes "We need you" and to asks them to "bring other animals and plants," the humility expressed is not to be diminished as childish innocence, but rather a powerful knowing of missing relational epistemologies and ontological intuitions (Young 2021, 4:07) that are necessary to (re)member and (re)imagine ways to (re)design structures and learning to be radically caring.

Design Principle 4: resistance and refusal as valued design practice

Throughout this study, students fundamentally asserted the need to axiologically (re)story sociotechnical design and development toward radical care for a futurity in peril, futurities denied and a futurity of becoming-with worlds (Haraway 2015). As indicated, this means that engineering and engineering education need to be unsettled by prioritizing principles of reciprocal kinship and establishing design criteria and practices that prioritizes the critical liberatory presencing of multispecies communities and LandAirWaterStars for socio-ecological justice. Such a (re)story would be revolutionary, as it materializes an ongoing design stance of resistance and refusal if development is determined to be unjust. This runs contrary to one of the teacher's perceived ideological struggle during instruction, summarized in their positivist comment, "I have to hold onto the belief that science, scientists and engineers are always trying to do good." Instead, students maintained that science and engineering endeavors must prove they are just and are always at risk of being disrupted

and/or denied. Clarity of this stance of resistance and refusal is evident in the following two student design meeting invitations and narrated responses.

[To: Environmentalist] You have been invited here to look at this train in your own perspective. It is a long maglev train that runs along beaches & forests. This meeting is important because we want to know a new view on helping the environment. I hope you can tell us what would be good for the people and the Earth. These are some questions for you to answer: What would this train do to hurt the environment and what can we do to help it? What can we do to help stop noise pollution? Thank you

[Response from Environmentalist] Destroying the forests and habitats for this train is selfish and absurd.

[Response from Sacagawea, “a revered cultural leader”] I know a lot about the land so if you want to hear my opinion come ask me! I am wise but I do not consider myself old, I am only 60. I would like to share my opinion to everyone to hear because I know a lot about the train and land!!! Though I am not used to modern things. Also I know a lot about the train from listening to train builders! I say No train! The land says to me that the mountain is calling for help, the forest too and the people are literally calling for help saying it will pollute the water, the mountain should not get hurt which is true.

In the first example above, the student sets up the environmentalist to provide information to substantiate the resistance and refusal of the train’s development by admitting that a counter perspective is needed to determine “what would be good for the people and the Earth” and “what can we do to help stop noise pollution?” The student then offers a demonstrative resistance and refusal from the environmentalist, stating, *“Destroying the forests and habitats for this train is selfish and absurd.”* In the second example, the student takes on the perspective of a revered cultural leader as protector of and speaker for the land, mountain, forest, water and people, refusing the development with the statement *“I say No train!”* Such powerful stances of refusal reflect antiracist and liberatory feminist approaches to engineering, in which “a creative solution is sought to benefit all community members, with the participation of all concerned, and proposed solutions are evaluated based on their contribution to the goal of social justice, recognizing that sometimes the best solution may be not to engineer in the first place” (Riley, Pawley, Tucker and Catalano 2009, p. 33). Students’ ongoing resistance and refusals of unjust development offer wise guidance to help ensure that technoscientific design agendas are oriented toward justice through radically caring engineering practices.

The instructional design of the stakeholder design meeting served to scaffold solidarities, as evident in above student examples, as well as scaffold opportunities for dissent to complexify and open up multiple perspectives, destabilizing authority and engineering norms. In the following invitations, students engage in a mode of questioning that asks figures of systemic authority to set up opportunities for other stakeholders to critique and challenge the authority figures’ value stances and potential alignment with settler ecologies.

[To: President of country] My question is do you think it will be worth the money and all the cons? Do you really want to hurt nature?

[To: Scientists] Train will hurt the environment and animals, but it will be better than cars, are you okay with this?

[To: Mayor] You are invited because we need to discuss why you are building the train.

[To: Engineer] Discuss train's cost, space & animal environments. They destroy plants & damage electricity lines...can you make trains take less space and can you make it impact less?

Students' critical questions posed to humans in understood positions of power act to level the playing field, so to speak, dismantling hierarchical, structural boundaries and barriers that perpetuate injustice by advancing hidden agendas of colonial progress (e.g., through development projects). Students' refusal to naively trust and respect those in roles of authority as agents of ethical and just leadership maps ontological distances and locations between pre-colonized and colonized mindsets. By centering engineering practices of resistance and refusal, humility and critiquing of neoliberal, utilitarian and capitalistic agendas, students were challenging and "delinking... from the colonial matrix of power" (Mignolo 2009). Ontological and pedagogical shifts that position students as co-constructors and co-designers of place and technology, void of preconceived notions and constraints of engineering, resulted in students manifesting revolutionary new ways to embark on engineering endeavors (Table 1).

Implications: (Un)learning and (un)(re)becoming with and for children

As we sink deeper into students' invitations, a foreboding narrative arises of becomings that never became or may never become. As educators, as adults, how and what have we (un)become as actors of settler colonialism? What ghosts of ourselves and youth do we unwittingly create when we perpetually require and standardize settler progress narratives and epistemologies that sacrifice student's ontological security and intellectual health? How can we (un)(re)become with ourselves, with youth and with LandAirWaterStars and multispecies that worlds a new otherwise.

By humbly sitting alongside students, as equals, and understanding the ongoing, new and yet-to-be challenges they are witnessing and facing, educators, curriculum designers and writers of standards have much to (un)learn and take critical response-ability (Kayumova and Tippins 2021) to address. Reflecting this understanding, this study leveraged the Critical Speculative Design Pedagogies framework to create lessons to counter the false narrative of a neutral curriculum and neutral instruction, understanding that "washing one's hands of the conflict between the powerful and the powerless means to side with the powerful, not to be neutral" (Freire, Giroux and Macedo 1985, p. 122). Through this decision, but more so through the honest and necessary strength and brilliance of the youth, those of us in engineering education have been given a gift of insight into not only what can be but what should be. In truth, "The time for arguing for a socio-politically engaged and transdisciplinary science education for multispecies survival is effectively over" (Wallace, Bazzul Higgins and Tolbert 2022, p. 4). The youth are waiting for us educators to desettle our own onto-epistemic selves, engage in critical reflection for critical flexion and step up to do so in science and engineering curricula in all learning spaces.

This study also illuminates, through the resilience, resistance and refusals of third-grade students, a new and urgent approach to science and engineering education that not only embraces multispecies and LandAirWaterStars justice for collective continuance, but also does so while exceeding learning standards in complexity and praxis. Given the pace of socio-ecological harm occurring due to settler ecologies of progress, it is time for NGSS, the NRC *Framework* and all engineering standards to be anticolonial, generationally

Table 1 Just worlding design principles with additional examples of student invitations

Design Principle 1: radical care of kindred relationality as design priority	Design Principle 2: critical and liberatory presencing of multispecies, LandAirWaterStars, and rights of nature	Design Principle 3: transparency and humility as valued design stance	Design Principle 4: resistance and refusal as valued design practice
[Trees] I want to invite the trees because trees are impacted by trains going through forests. Trees have to be cut down when trains go through forests. A perspective they might share is that trees are important to the ecosystem because they provide homes for animals a clean the air so when trees get cut down it hurts not only the tree but also the animals	[Animals affected by train & an animal translator] They are being invited because their homes might be destroyed and could get killed also the animal translator because how are [we] going to be able to understand them. It's important they come so we can talk about cleaning out their homes and stay out or the way. Animal translator so they can understand each other. I hope they are so cute that they change the route of the mag lev train so that it will not go into their homes.2 questions I want them to answer are If they are okay with us blowing up their homes and how does an animal translator understand the animals?	To Mr. Willy the Mountain, you are being invited to the annual Maglev revision day. This Maglev will be cutting through part of your body. We will interview you on how you would like to revise this Maglev. We hope you share your ideas with us. Some questions we might ask you are: 1. Do you like this train, if so, why do you like it? 2. If you had to change this train, how would you do it and why?	[Trees] I have invited you to help us at the N.S.C (Nister Science Co.) to make it [the train] better for you and your family. To tell you about this train, it runs at a speed of 1G8mph. Please come because we need your help to design it, and way more, I hope you will tell them not to break forests. You will have to answer two questions. 1. why you came to the meeting? 2. what do you want to change for this train?
[Squirrels] We think it may hurt the environment, we would like to know how you think of it PS the birds will be there to discuss importance of trees	[River] You are invited to discuss problems of the Maglev train, one reason you should come is to make it better and it affects your problems. We want to talk about how you think we should fix your problems	[Citizen] Share what you don't like about the train Do you think it is too expensive? We think we need your permission. You should know it will help people get to work fast but it is bad for the environment	[Fishey] You will give us a very new perspective because everybody else is a human. Do you already have other ideas for paths? Do you think we should cancel the whole idea? By the way you may bring other animals and plants

Table 1 (continued)

Design Principle 1: radical care of kindred relationality as design priority	Design Principle 2: critical and liberatory presencing of multispecies, LandAirWaterStars, and rights of nature	Design Principle 3: transparency and humility as valued design stance	Design Principle 4: resistance and refusal as valued design practice
<p>□Dear Luna & Midnight, (Wolves) Please attend this design meeting for the train. It would make this meeting so much better if we heard your & your pack's ideas. What do you think we should add, and what should we remove?</p>	<p>[Trees, Waterfalls, Rivers] You are being invited because the train is going to impact you guys! Yay, Wa-hoo you guys are going to help us with how to make the train better, the train is going to be cutting through some farmland and will be near some people and people will have to blow up nature.</p> <p>Please help to come up with some ideas to save you!</p>	<p>[Farmers] We want to talk to you because we have a problem think you should come bc you are a stakeholder and we are making an impact in your environment. The impact is that we are building a massive train Of course, before we release it we want to talk to all the stakeholders</p>	<p>I think Mr. Animal should join fip, he is rooting for the trees to stay alive and he thinks that his home will be destroyed because of the mountain [being blown up] he will answer the questions where his home is in the forest and why he thinks that the train idea should be terminated!</p>

competent and radically caring. Movement toward this belated need can and should be guided by the four design principles of engineering that the students in this study provided.

The four design principles of, *honoring kindred relationality as design priority, critical & liberatory presencing of multispecies, LandAirWaterStars & rights of nature, transparency & humility as valued design stance, resistance and refusal as valued design practice*, provide engineers, the field and education of engineering new and urgent design and development priorities and practices. As has been mentioned, engineering has for too long been a field that has actualized and materialized colonial plans of socio-ecological consumption and dominance. The design principles that the youth in this study offer provide the field a heart, a pulse within cyborgs and cyborg-making practices, not only capable of empathy but also new, creative Landscapes for dreaming and developing, “critical for developing climate-adaptive planning tools and narratives for the creation of socially and environmentally just multispecies cities” (Houston, Hillier, MacCallum, Steele and Byrne 2018, p. 191).

Conclusion: Designing beyond “situation critical” toward kincentric flourishing

What is the world beyond coloniality and human supremacy? What worlds can we (re)imagine and (re)generate through the dissolution of the tendrils of settler ecologies in our minds, classrooms, and technoscientific innovations? Designing for worlds of multispecies flourishing requires radical caring that foregrounds the socio-spatial histories and futures of LandAirWaterStars and multispecies and positions humans as agentic beings for collective flourishing, as best we can. This means that the planning, (re)designing and (re)development of all spaces must prioritize the well-being of more-than humans, humans, and LandAirWaterStars through relational and reciprocal epistemologies. Youth ontologies and logics of radical care asserted in this study offer alternative worlding and multispecies justice frameworks for engaging in this urgent work within the fields and education of engineering and planning theory. Planning and designing for socio-spatial justice means disrupting settler conceptions of progress that betray and deceive us (Kayumova, McGuire and Cardello 2019) and illuminating the points of convergence of relational complexities between humans, multispecies and LandAirWaterStars, not as points of divergence, but as points for expansive radical care needed for (re)imagining an *otherwise*.

To (re)make these endeavors requires centering educational experiences and research outside the confines of reductive, dominant science, and engineering lessons. Learning opportunities can be created to expand and contribute pedagogies and methodologies that reconfigure power and purpose to promote new imaginings of engineering for collective continuance—the culturally grounded, moral pursuit of rightful relations (Whyte 2018). Providing students with an authentic and consequential place-based context had the power to disrupt the onset of colonial mindsets and illuminate the foolishness and short-sightedness of settler colonial ecologies.

Considering “discipline is empire” posits pedagogies and standards as epistemic borders that close horizons of expansive learning and being (McKittrick 2021, p.36). To move beyond these boundaries and epistemic supremacy, this design-based research purposely embedded learning engagements aligned to multiplicity, horizontality, and dialogicality—the three dimensions of radical heterogeneity within the westernized classroom spaces and curriculum (Warren, Vossoughi, Rosebery, Bang and Taylor 2020). This unit situated

the curricular phenomena of a maglev train outside the enclosures of settled science and technocratic engineering design cycles and instead moved it into global socio-ecological Landscapes and realities. As a result, westernized knowledges and practices were no longer positioned as singular and supreme, opening space for multiplicity by inviting multispecies, community, and LandAirWaterStars knowledges. The desettling of westernized disciplinary frames opened up space to provide dialogicality through engagements of perspective-taking for meaning-making and created “a critical site of refusal, delinking, and re-imagining the normative chains that structure disciplinary learning.” (Warren, Vosoughi, Rosebery, Bang and Taylor 2020, p 285).

The recognition and respecting of students, marginalized community members, multispecies, and ecological entities as critical actors in technoscientific decision-making provided scaffolds for epistemic disobedience and the re-storying and repurposing of engineering goals to be grounded in radical care for worlding common worlds (Nxumalo and Pacini-Ketchabaw 2017). As educators and radical individuals, “We cannot continue to build a world on the backs of children while denying their right to live in it” (author unknown). Disrupting settler colonialism in science and engineering education means demanding standards and practices that bring in multispecies justice frames for kincentric flourishing.

Appendix

Final Assignment: Stakeholders Design Meeting Invitation

Jan. 25th/26th Science - Invitations to the Design Meeting

In this activity you will write an invitation to a stakeholder in the Kuala Lumpur-Singapore train project (train article #2) to a design meeting.

1. On the first page add **T** to say who you are inviting to the design meeting (which stakeholder?).
2. One the next page, add **✉ T ★ ↗** to create a letter (or a card) inviting that stakeholder to come to the design meeting. Use the tables on pg. 3 & 4 to help you (they are the notes from our class meetings).
3. Be sure to include in your invitation:
 - An explanation of why they are being invited and a little about the train.
 - Why it is important that they come.
 - What unique perspective you hope they share.
 - At least 2 questions you want them to answer.
4. Don't be afraid to get creative with who your stakeholders are (people, animals, or even nature all count!) and how you invite them!
5. Extra Credit: On page 5 tell about any design improvements for this train that would benefit the stakeholder you invited.

Assignment Page 1

invitation

Who is your invitation going to? (the stakeholder)

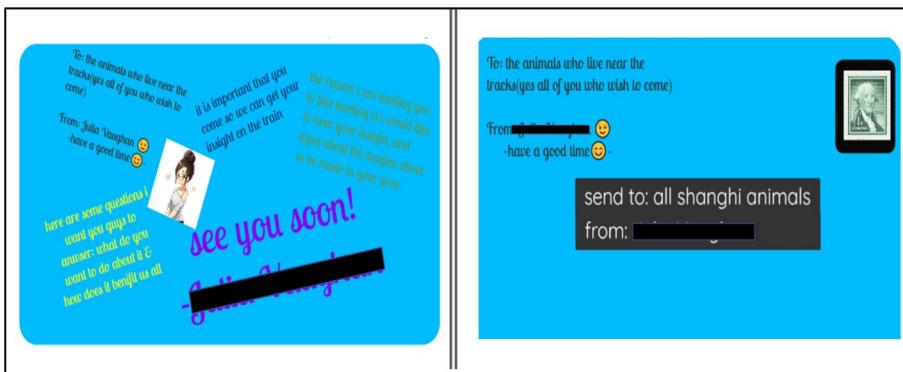
To:
From:

Assignment Page 2

Write your invitation below. You can include text, shapes, and images.

Example of digital format for students' stakeholder invitations:

To all animals who live near the tracks (yes all of you who wish to come), the reason I am inviting you to this meeting is I would like to hear your insight, and input about the maglev train about to be made in your area, it is important that you come so we can get your insight on the train, here are some questions i want you guys to answer: what do you want to do about it & how does it benefit us all? See you soon have a good time 😊



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Declarations

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