Rethinking Transdisciplinarity in the Learning Sciences: Critical and Emergent Perspectives

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Abstract: This symposium advances the discussion on transdisciplinarity as a key theoretical construct to disrupt hegemonic disciplinary silos in the learning sciences and to open up equitable and inclusive disciplinary practices that make visible the silenced voices and hidden histories. This symposium is a collection of five papers connected to the central notion of transdisciplinarity: 1) social design as transdisciplinary praxis, 2) fostering epistemological junctures in STEM through transdisciplinary design with young children, 3) centering voices of Latinx women's intersectional becoming to reconfigure STEM disciplines, 4) heterogeneous and transdisciplinary learning with Inuit youth through community-driven youth programs, and 5) multimodality as transdisciplinary design to reframe disability in school science. By gathering researchers who draw from diverse epistemologies and methodologies, we will unpack the notion of transdisciplinarity and its relevance to the learning sciences.

Introduction: (Re)defining transdisciplinarity

With its roots across multiple disciplines (cognitive science, computer science, design, anthropology, sociology, educational psychology and critical historical perspectives), interdisciplinarity is one of the defining characteristics of the International Society of the Learning Sciences. The research of learning, teaching and longitudinal development are inherently heterogeneous and transdisciplinary in the sense that none of these phenomena can be adequately described from the confines of a single discipline (Sengupta, Dickes, & Farris, 2018; Lehrer & Schauble, 2012). The goal of our symposium is to (re)define disciplinarity and inter/trans-transdisciplinarity within the learning sciences. While interdisciplinarity and transdisciplinarity are often interchangeably used, in this symposium, we intentionally use transdisciplinarity to emphasize how our works can transcend traditional disciplinary boundaries. For us, transdisciplinarity refers to reflexive and emergent relationships achieved through freeing the hegemonic disciplinary practices (Takeuchi, Sengupta, Adams, Shanahan, & Hachem, submitted).

We start our discussion by posing a fundamental question: What is "discipline"? Discipline, as discussed in Pickering (1995), enables humans to extend their conceptual practices: "Disciplines — acquired in training and refined in use — carry human conceptual practices along, as it were, independently of individual wishes and intents" (p.115). Disciplined ways of using cultural tools and representations allow humans to express or participate in complex conceptual and representational practices. In this sense, discipline is agentive, enabling, liberating and productive. Yet, disciplinary practices can be constraining and hegemonic and can potentially serve against heterogeneity. Etymologically, the term discipline comes from the Latin word "discipulus" that originally meant "to educate" and connotes "processes of control" (Gordon, 2006). Foucault (2009) also states that "discipline is a mode of individualization of multiplicities" (p.12). In academia, disciplines tend to be organized as independent departments with rigid structures and hierarchies. Historically, the system of academic disciplines has been functioning to individualize human subjects. Human impetus in knowledge-producing practices, its commitment to fundamental societal problems, and living dialogues among disciplinary-enabled subjects can be lost in such fallacy of constrained and isolated disciplines.

The current institutional system of discipline has been entangled with geo-political configuration of the world. As Mignolo (2009) maintains, disciplinary practices have long been linked with the colonial matrix of

power, by detaching epistemology from the geo-political configuration of the world that people, languages, and knowledge that are racially and geographically ranked. Reflexive transdisciplinary practices call for scrutinization of the current and historical disciplinary practices that have reproduced the geographically and historically marginalized; in this sense, transdisciplinary heuristics are fundamentally critical (Strong, Adams, Bellino, Pieroni, Stoops, & Das, 2016). From this perspective, liberation of discipline toward critical transdisciplinarity is to relinquish geo-political constraints and to aim for spatial expansion of epistemological boundaries.

Inviting interactions across disciplinary boundaries create a new space of encounters and interactions — in the same way that the places where different fluids meet and create a boundary layer (Shanahan, 2011). The creation of this boundary layer can interrupt disciplinary hegemonies and can also lead to the emergence of new concepts, representations, and applications, that ideally should also re-centre voices from the margins (Sengupta, Shanahan, & Kim, 2019). An integral part of this boundary work involves redressing the historical and systemic violence and barriers experienced by people from non-dominant groups in accessing disciplinary practices (Bang & Vossoughi, 2016; Gutiérrez, 2008; Kayumova, McGuire & Cardello, 2019; Lee, 2008; Leyva, 2017; Nasir, 2011; Rahm, 2010; Rosebery, Ogonowski, DiSchino, & Warren, 2010; Takeuchi, 2018). In this sense, historical epistemology, "learning to 'see' historically across multiple time scales" (Gutiérrez, 2016, p.190), is fundamental to imagining critical transdisciplinarity within the learning sciences.

All the papers in this symposium are tied together by a common theme on rethinking the meaning of transdisciplinarity in their epistemology, design, and methodology, especially from the lens of disrupting the hegemonic disciplinary practice within or beyond the learning sciences. Yet, these papers shine light on different aspects of transdisciplinarity. They bring diverse epistemologies and methodologies to approach transdisciplinarity, instead of achievement of a unified and monolithic perspective. In this sense, this symposium aims for emergence of divergent perspectives toward transdisciplinarity. We embrace tensions and differences among us, and we hope that such tensions will evoke productive and holistic discussion on transdisciplinarity. Co-chairs will start with brief framing of transdisciplinarity (5 minutes), and authors will present their papers for 14 minutes each, followed by 8 minutes of commentary by a discussant. Remaining time will be reserved for open discussion with the audience.

Fostering epistemological junctures when designing for transdisciplinary learning

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STEM education is currently segregated by discipline and even when transdisciplinary learning is designed, as in integrated STEM education, learning opportunities often are lost in the resulting mix (National Academy of Engineering and National Research Council, 2014). Recent efforts to improve instruction in STEM disciplines emphasize a turn toward practice, positioning students to participate in approximations of the epistemological means by which STEM professionals generate and revise knowledge. With these epistemological means in mind, I suggest that students participate in shared practices across disciplines that reveal common means of making and revising knowledge, but where disciplinarily distinctive differences in ontologies generated by these common practices are also visible to students. The anticipated effect is a form of resonance, here intended to convey a sense of greater amplitude of learning as a result of harmonizing, but not merging, disciplinarily distinctive epistemologies.

To explore the implications of this intention, I consider two illustrative cases of students' experiences of transdisciplinary in mathematics and in sciences. The first case describes how over the course of two years, young children participated in common practices of representational re-description of experiences in mathematics and in sciences (Greeno & Hall, 1997). In mathematics, these involved children's invention and contest of ways of representing measured quantities and of ways of coordinating measured quantities, both of which were governed by relations of necessity (e.g., children decided that all points on a line in a Cartesian graph represented the same ratio between quantities, such as the circumference and height of collections of cylinders). These representational means were extended in sciences to new quantities to describe plant growth and the densities of different materials, providing new ways for children to conceive of these natural systems (Lehrer, Schauble, Carpenter, & Penner, 2000).

In the sciences, the ontological status of the mathematical systems developed to describe space and coordination of spatial measures changed from necessity to approximation. For example, lines in Cartesian space modeled relations between mass and volume, yet the coordinated measures of the same material kind did not all fit exactly on a line, suggesting the children that such misfit was due either to error in measure or perhaps because the material was not in fact all of the same kind. This experience of uncertainty is at the foundation of the open-

textured nature of modeling noted so often in the philosophy of science (Hesse, 1962). Children's investigations in science also spurred extensions to mathematical systems, so that on the one hand, by practicing representation in mathematics, students had conceptual means to reveal new and unanticipated qualities of natural systems, but on the other, students' use of these mathematical systems as stand-in's (models) for natural systems spurred mathematical innovation and elaborations of mathematical systems. For instance, to accommodate the need to compare three quantities simultaneously to characterize the growth of plant roots and shoots, children proposed expanding the Cartesian system from one quadrant to two, albeit in unconventional ways.

The second case describes how sixth-graders engaging in the practice of modeling the variability of data generated in diverse settings and variability-generating processes of measure, production, psychophysics, and biological sciences, came to appreciate modeling observed variability as approximating a process involving non-random and random components. Yet this approximate ontology also promoted transformations in the mathematical logic of sample as necessarily hierarchical, where sample was conceived of as simultaneously representing a particular set of outcomes and as one of an infinite number of possible sets of outcomes generated by a process (Lehrer, 2017). In sum, for both younger and older children, participating in multiple disciplines amplified learning within each discipline, yet also provided students with opportunities for first-hand experience of disciplinarily specific ontologies. This form of harmonization created epistemological junctures that unfolded over time during the course of instruction.

Youths' relationships with the land, each other, and their community: A critical lens and engagement with the transdisciplinary and heterogeneous

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The Cartesian study of learning and becoming in science has ensured a focus on the individual and the individual as apart from, rather than in relation to, and with others, the community, or the land. Youth themselves have been codified in particular ways in the literature with an emphasis on what they fail to do instead of focusing on the intersections of their personal, social, political and pedagogical embodied actions tied to agency and transformation. In this paper, we develop a different narrative grounded in a transdisciplinary discourse with a focus on the heterogeneous learning lives of Inuit youth in Nunangat (Kalluak, 2017). We do so through a focus on a community driven youth program developed by Inuit to respond to a community need, a program that then contributed in important ways to local capacity building and leadership. We rely on qualitative data gathered over time (Interviews and informal dialogue from 2014 onward), with youth participants and their mentors in the Young Hunters Program which engages youth with their land, culture, and community through trips on the land, dialogue with elders, and the fabrication of culturally relevant materials. The program also engages youth in environmental stewardship (e.g., monitoring of health of country food through necropsy, etc.). The project is embedded in the complex political fabric of education in Nunavut, in part assumed by Inuit, yet still deeply grounded in Western ways. It is for this reason that the project calls naturally for a grounding of its story in multiple disciplines and a relational epistemology.

Through stories of learning and becoming within those two program dimensions (Young Hunters & Environmental Monitoring), we engage in the documentation of learning and identity work deeply grounded in a holistic worldview and de-colonial reading of educational success. Through a space-time reading of learning and becoming, we also engage with lifelong learning at multiple scales, paying attention to the interrelations of youth with the land, with each other, and with their community (Tagalik, 2011). We offer new insights into why the current educational system fails youth, and in doing so, move beyond a positioning of youth as failing.

In conclusion, we reflect on our own positionality in this research endeavor and the contradictions long-term respectful and collaborative projects and commitments to communities in Nunangat imply, once deeply grounded in and committed to indigenous methods, and reciprocal and respectful relationships with the land and culture, and the care of each other (Wilson & Hughes, 2019). That kind of relational accountability, however, contradicts current institutional pressures for fast paced research practices. In fact, higher education defines such work as soft science and perceives of youth and community voice driven research as too subjective. To bring such contradictions to the foreground, however, can result in new possibilities and social change driven by and committed to equity and social justice, as we will make evident in this paper.

Intersectionality as transdisciplinary methodology: Voices of Latinx women in mathematics

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With Latinx women underrepresented in engineering, computing, and mathematical sciences (Espinosa, 2011), where undergraduate mathematics is a racialized-gendered gatekeeper, understanding undergraduate Latinx women's mathematics experiences can illuminate influences on their positive identity constructions and persistence in these fields. This presentation shares findings from a study of two Latinx women (Diana and Zoila) negotiating their social identities with mathematics success as engineering majors at a large, predominantly white university in the U.S. Northeast.

In pursuing a critical transdisciplinary analysis, the study synthesized interdisciplinary theories and methodologies to propose creative, socially responsible solutions for the "wicked problem" (Brown, Harris, & Russell, 2010) of retention among historically marginalized groups, including Latinx women, in STEM (science, technology, engineering, and mathematics). Theoretically, intersectionality from Black feminist thought guided inquiry about how culture, gender, and race shaped the Latinx women's experiences (Crenshaw, 1991). Counter-storytelling, a methodology from critical race theory (Solórzano & Yosso, 2002), was adopted to construct analytical narratives of Diana's and Zoila's intersectionality of experiences. We also drew on the methodology of field observations from cultural anthropology to contextualize the two Latinx women's self-reported insights through individual interviews and a focus group, which contributed to the construction of the study's counter-stories. A critical transdisciplinary cross-case analysis of the counter-stories illuminates ideological, institutional, and relational influences on Diana's and Zoila's intersectionality of experiences.

Ideologically, Diana's and Zoila's counter-stories illustrate variation in their negotiations of identities with discourses of mathematics ability as innate, gendered, and racialized. Diana disagreed about "hav[ing] to be smart to be successful" and described her responsibility as a Latinx woman to inform younger marginalized students about her racialized-gendered STEM experiences – an intersectional obligation that she felt her Latinx brother in engineering did not share as a man. Zoila, in contrast, attributed being one of few Latinx women in advanced mathematics classes to her innate talent that other Latinxs lacked. Such intersectional negotiations extend prior findings about Latinx women's race-based (namely, color-blind) interpretations of experience.

Institutionally, the Latinx women reflected on racialized-gendered double standards of who can occupy space in mathematics classrooms. Observations in Diana's calculus recitation documented a white man who shouted answers and corrected the instructor. Diana characterized this student behavior as not readily taken up among Latinxs, while arguing the instructor would likely acknowledge the white man with comments like "Not all of us are as quick." When Diana similarly "voice[d] her opinion" that challenged her mathematics professor, she described feeling that classmates positioned her as "bossy." Such discrepancy between how Diana felt the white man's and her contributions were received illustrates how mathematics classrooms can operate as white, masculinized spaces with racialized-gendered bids for participation.

Relationally, racialized-gendered framings of mathematics ability brought Diana and Zoila to manage psychological burdens of how their contributions would be interpreted and affect others. Zoila, for example, experienced tensions about breaking whole-class silences following instructors' questions because she was concerned about "mak[ing] other people feel bad for not understanding." However, opportunities to more actively participate brought Zoila to re-consider feeling "intimidated by white people," whom she viewed as naturally smart. Thus, broadened opportunities for participation may challenge racialized-gendered discourses of ability that, in turn, lessen the riskiness of participation and increase mathematical engagement among Latinx women.

Overall, this study's coupling of Latinx women's reflections and mathematics classroom observations provide situated insights into multi-level influences that shaped Latinx women's intersectionality of experiences as mathematics students and engineering majors. Implications inform race- and gender-conscious teaching practices in undergraduate mathematics that affirm Latinx women's intersectionality of STEM experience.

Transdisciplinarity in social design-based experiments

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In this paper, we argue the affordances of transdisciplinarity with reference to *horizontal* and *vertical* forms of competence and expertise (Engeström, 1999; Gutiérrez, 2008), both in terms of their development in youth from non-dominant backgrounds and in design of transformative learning ecologies for said youth. To elucidate the importance of advancing a transdisciplinary-oriented lens to examine the ways in which non-dominant youth (re)negotiate their learning, agency, and identities within and across contexts, we situate our discussion in relation to social design-based experiments (SDBEs) as developed by Gutiérrez (2008, 2016, 2018, Gutiérrez & Jurow, 2016, Gutierrez, Jurow, & Vakil, in press). With a focus on historicity, diversity, equity, re-mediation, prolepsis, transformability and sustainability as design principles, SDBEs represent a paradigm shift in conducting educational and social interventions by emphasizing the importance of creating and studying change in partnership with a range of communities wherein new practices and futures can be co-designed. While it is beyond the scope

of this paper to provide a comprehensive account of SDBEs as a generative and ecological framework to transcend traditional disciplinary boundaries, we aim to bring to the fore in our work the syncretic nature of SDBEs, which, as argued by Gutiérrez (2018), involves "a synthesis of contemporary cultural life with history, the everyday with the more formal" (p. 14, see also Gutiérrez, 2014).

To illustrate the syncretic underpinnings of SDBEs and their implications for envisaging a transdisciplinary turn in learning sciences and design-based research, we provide in this paper a set of empirical vignettes that draw attention to the hybrid and mobile dynamics embedded in nondominant youths' sociocultural development and learning as youth leverage digital media and technologies to challenge the social order in their everyday lives. In particular, we examine how the forms of agency indexed in the nondominant youths' engagement with digital technologies can be understood through the analytical lens of becoming historical actors (Espinoza, 2003; Gutiérrez, 2008; Gutiérrez, Becker, Espinoza, Cortes, Cortez, Lizárraga, Rivero, Villegas, & Yin, 2019) where youth negotiate everyday dilemmas, push against the intentions of systems and their designers (Harrell, 2013), repurpose tools toward new ends, and resist local and historical sociopolitical inequities. In alignment with the syncretic nature of SDBEs, our examination sheds light on the affordances of perceiving agency as a distributed phenomenon, involving the deployment of vertical and horizontal expertise, particularly in our increasingly interconnected world. Echoing our previous work that attends to the circumstances under which learners can be regarded as historical actors (Espinoza, 2003, 2008; Gutiérrez, 2008), we argue that the analytic of becoming a historical actor, as presented in this paper, dovetails with the transdisciplinary agenda proposed in the symposium through its explicit commitment to equity and attention to the history of nondominant youths' involvement in everyday resistance practices (Gutiérrez, 2016; Pacheco, 2012). As highlighted in our preceding descriptions of the design principles of SDBEs, attention to equity and historicity reminds us to focus on moments that have often been relegated to the margins or deemed unimportant to consequential learning (Jurow & Shea, 2015). In this vein, we foreground the everyday as a site of powerful learning and development, where novel and socially oriented forms of agency can emerge.

Of significance to our discussion of SDBEs, we believe that the transdisciplinary turn in learning sciences entails a critical recognition of the dialectical relationship between scientific (school-based) and everyday concepts and the potential of bringing the two in conversation through their reorganization. The relationship is dialectical in the sense that, one the one hand, scientific concepts structure the pathways for the development of everyday concepts. On the other hand, everyday concepts grounded in everyday activity have the potential to become the contexts for the development of scientific concepts. Therefore, what lies at the heart of our conceptualizations of syncretic approaches to design is an imperative call for re-negotiating and productively hybridizing the everyday knowledge vis-a-vis school-based skills and knowledge to cultivate expansive and consequential forms of learning.

Transdisciplinarity as multi-modal reimaginings of deficit framings of disability in school science

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This critical review paper explores the possibilities inherent in the multi-modal ways of knowing and creativity of disabled students in rethinking the relationship that disabled students are thought to have with scientific knowledge and practices. We offer a transdisciplinary account through integrating literature in critical disability studies, human computer interaction, and scientific modeling, and ask how the everyday representational practices that disabled children engage in with assistive and communicative technological devices are deeply synergistic with practices that are central to modeling in science education.

Disabled students in science are most often positioned as deficient, needing assistance and accommodations to participate in science learning activities (McGinnis & Kahn, 2014). Technology integration in that context typically takes the form of asking whether the simple introduction of digital tools, such as ipads, can facilitate adaptation of conventional science pedagogy to meet disabled students' needs (e.g., Miller, Krockover & Doughty, 2013). In this perspective, disability is located within the student, and the practices and concepts of science must be altered to allow them to participate. Approaching inclusive science and science education as a problem of accommodation, however, ignores the ways in which disabled students have already developed deep understanding of the articulations between science and technology that are rich resources for, not barriers to, science learning (Jackson, 2018).

One group of students that has been almost left out of inclusive science education research is users of augmentative and alternative communications (AAC) technologies. The term AAC is used to describe a variety of tools, from picture-based communication books to voice output devices, which generate spoken words from user-inputted symbols, typing or predictive text. They are often used by students with autism spectrum disorders,

cerebral palsy, apraxia of speech and other disabilities that can impact expressive language. With the growing availability of more affordable consumer products and app-based programs that can be used as AAC devices (smart phones, tablets, etc.) digital AAC users, in particular, are a growing student population (McNaughton & Light, 2013). Challenging typical deficit framing of AAC users, Higginbotham (2009) illustrated the complexity and richness of conversations of between AAC users, non-AAC users and communication partners in terms of the multimodality of symbolic, gestural, material and linguistic representational resources in order to establish common ground (Ibrahim et al. 2018).

Beginning to imagine how AAC users might be repositioned as knowers and creators whose contributions are valued in classroom scientific communities means stepping back to ask what it means to do science. Philosophers of science (e.g., Giere, 2004) have argued that modeling is the central practice of science and scientists. Models are a specific kind of representation — the language of science (Giere, 2004) — iteratively developed, whose elements (such objects and processes) become analogues for features of the natural world, and scientists leverage the similarities between these models and the natural world to generate hypotheses and test generalizations about natural processes (Giere, 2004) through repeated layering of multimodal discourses (e.g., Lemke, 1998), in ways that deeply intertwine epistemic and representational practices (Pickering, 1995). Science educators argue that in order to deepen students' expertise in authentic scientific practices, modeling in science classrooms must be practiced systematically so that a variety of forms of models (e.g., graphs, physical and embodied models) and uses of models (e.g., simulation, prediction, verification, etc.) are explored and evaluated by students as meaning-making practices (Lehrer & Schauble, 2006).

Specifically, in the context of K-12 science education, researchers have shown that multimodality and interdisciplinarity are central to developing deep scientific expertise for K-12 learners (e.g., Rosebery et al., 2010). Examples involve the use of multiple symbolic representational systems, embodied, physical and computational modeling (Lehrer & Schauble, 2006), the complementarity of refining scientific work through the refinement of mathematical representations (Danish, 2014), and the reciprocal relationship between engineering design and scientific modeling (Sengupta, Dickes & Farris, 2018). We propose that the emphasis on multimodality as a central feature of scientific modeling has the potential to be deeply synergistic with the representational practices of AAC users in a way that can contribute to re-understanding AAC users as unique and valued actors in classroom scientific practices. There is ample evidence in the literature on AAC users' communicative strategies that suggest that AAC users are continuously engaged in interpreting, adapting, and creating multimodal representations (Higginbotham, 2009; Ibrahim, Vasalou & Clarke, 2018). That is, the choice of a single word on an AAC device often emerges from a heterogeneous set of actions that involve multiple modes of representational communication such as gestures and diagrams, as well as sophisticated and sometimes subversive repurposing of symbols, words and sounds to communicate analogical meanings or assert agency within an interaction (Doak, 2019). These representations are also socially mediated and created as public artifacts (Higginbotham, 2009). This paper presents a conceptual analysis of the intersections of how multimodality is taken up in studies of AAC users and of scientific representation in schools, culminating in a framework for conceptualizing how modelling experiences in school science can *begin from* (rather than merely accommodate) the already complex understanding and experience of representation of AAC users.

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