Principal Components Cartography for Material Change

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Abstract

In this study, we bring quantitative analytical techniques and a large survey dataset into conversation with the principles of radical cartography, a post-qualitative methodology for social justice. Through cartography, we explore what science classroom practices might provide the basis for patterns of relationality that subvert the unjust relations of the status quo. We describe how radical cartography facilitated a productive re-engagement with a dataset that had resisted our previous analyses, and we articulate what types of assumptions, commitments, techniques, and conclusions might be congruent with using quantitative data as the basis for radical cartography. Finally, we offer cartography-driven recommendations for science teaching to support minoritized students in overcoming systems of oppression, particularly in areas beset by anti-DEI policies.

Objectives

In this study, we bring quantitative analytical techniques and a large survey dataset into conversation with the principles of radical cartography (Kuntz, 2018), a post-qualitative methodology meant to develop "an ethical relation to change that productively challenges and disrupts the exploitative processes we now endure" (p. 2). Our engagement with radical cartography began from a desire to help educators who worried that anti-DEI policies threatened their abilities to promote gender and racial equity in science and resist hierarchical systems of oppression. Through cartography, we explore what science classroom practices might provide the basis for patterns of relationality that subvert the unjust relations of the status quo. The principles of radical cartography suggested the possibility of a productive re-engagement with a dataset that had resisted our previous analyses, thus our objectives in this study are twofold: 1) to develop a specific approach for using quantitative data and inferential statistics as the basis for radical cartography; and 2) apply this framework to a large dataset with the aim of identifying recommendations for justice-oriented science teaching practice. Specifically, we articulate what types of assumptions, commitments, techniques, and conclusions might be congruent with using quantitative data as the basis for radical cartography. Finally, we offer cartography-driven recommendations for science teaching to support minoritized students in overcoming systems of oppression, particularly in areas beset by anti-DEI policies.

Theoretical Framework

Relational materialism is an onto-epistemological framework used to explore complexity, tension, and contradiction–situations that typically require synthesis and reduction–to create possibilities for social change that are not readily apparent in our current context. Kuntz (2018)

articulates relational materialist inquiry as comprising "two distinct practices: 1) mapping relations that sustain [a particular pattern of relations]; 2) establishing arenas of potential for new creations, new potentialities" (p. 3). Through relational materialist inquiry, we aim to access *potential* that is latent but present in our contemporary relations, thereby exceeding the current limitations of being: our collective imagination, capacity for communal affirmation, and action to overcome the status quo. Accordingly, "mapping" within relational materialism is not undertaken to capture and define. We use mapping to document the practices and relations that inform our common sense of how to navigate the social world, with the aim of working outward toward the limits of our representational ability - the edges of the map. From the edges of maps, we may become attuned to "the way in which things are leaking out-not so that we can capture them, but maybe that we can follow their trajectories" into arenas of potential (Kuntz & Wooten, 2023, p. 92). In this paper, we refer to developing "leaky" maps as "radical cartography," another term used by Kuntz (2018).

Kuntz's methodological writings on relational materialism (Kuntz, 2016, 2018, 2022) are principally concerned with qualitative research methodologies. We contend that relational materialism is congruent with quantitative data and techniques of inferential statistics. Within a qualitative context, a methodological challenge of radical cartography is to generate sufficiently nuanced and complex maps: patterns of relations characterized by tension, contradiction, and uncertainty. We see this desired complexity as typical within many quantitative contexts. Take, for example, high-dimensional data. A common and sensible practice is to explore mechanisms for dimensional reduction to accomplish the complementary aims of reducing model complexity and decreasing sparsity. The notion of maintaining complexity to follow maps to new arenas of potential led us to consider what else we might do with data for which we would typically

consider reduction technique[s] a necessary first step toward achieving comprehensible and significant results. As critical scholars, we take seriously the materialist postulate that "the commonsensical reduction of difference into the blurred space of imagined consensus [fails] the critical project" of producing something beyond our status quo of unjust hierarchies of oppression and environmental damage (Kuntz, 2018, p. 26).

Methods and Modes of Inquiry

We explore an alternative use of Principal Components (PCs) of high-dimensional data (19-dimensional, in our case) to engage in radical cartography. After generating the PCs in standard fashion (i.e., rotating the coordinate space of our data along the axes of maximum variation), we do not reduce the number of PCs to analyze based on their ability to explain some fraction of the overall variance (Harlow, 2014). Instead, we examine the rotation matrix to identify PCs along which of our variables of interest exist in general alignment. We use biplots (Greenacre, 2010) to visualize the relations in our 19-dimensional data space, as projected onto the plane of PCs that met our criteria for exploration. We understand the biplots as leaky maps suitable for radical cartographical exploration (Kuntz, 2018).

Data Source

The data in this study were collected through a national research project, [blinded], which surveyed a general population of first-year college students enrolled in a required English course. The survey was administered at a stratified random sample (based on size and 2-year/4-year designation to reflect national student enrollment patterns) of 119 colleges/universities across the United States. In total, 15,725 students responded to the survey in Fall 2017. We used the survey

items that collected information about individual students' gender and racial/ethnic identities, the degree to which they enjoy activities related to science, technology, engineering, and mathematics (STEM), and their ratings of 16 potential career attributes on a 6-point Lickert scale. Figure 1 shows the 4 STEM enjoyment and 16 career items as they appeared on the survey. The STEM enjoyment items were previously validated as part of a STEM identity metric [blinded]. Accordingly, we created a single variable to represent STEM enjoyment, using the mean of each student's response to the 4 STEM enjoyment items, then created dummy variables to represent minoritized identity attributes within STEM careers: female and non-binary gender identity, and Black or non-white Hispanic racial and gender identities.

Figure 1

Career Satisfaction Attributes and STEM Enjoyment Items

Q2. Rate the following factors in terms of their importance for your future career satisfaction

	Not at all important 0	1	2	3	4	5 Extremely important
Making money	O	O	O	O	O	O
Becoming well known	O	O	O	O	O	O
Helping other people	O	O	O	O	O	O
Having others working under my supervision	O	O	O	O	O	O
Having job security	O	O	O	O	O	O
Working with people rather than objects	O	O	O	O	O	O
Inventing new things	O	O	O	O	O	O
Developing new knowledge and skills	O	O	O	O	O	O
Having lots of family time	O	O	O	O	O	O
Having lots of time for myself/friends	O	O	O	O	O	O
Making my own decisions	O	O	O	O	O	O
Having an easy job	O	O	O	O	O	O
Having an exciting job	O	O	O	O	O	O
Making use of my talents/abilities	O	O	O	O	O	O
Working in an area with lots of job opportunities	O	O	O	O	O	O
Having a creative job	O	O	O	O	O	O

Q22. To what extent do you disagree or agree with the following statements Columns

	No, Not at all					Yes Very much
	0	1	2	3	4	5
Topics in STEM excite my curiosity	O	O	O	O	O	O
I enjoy learning about STEM	O	O	O	O	O	O
I like to know what is going on in STEM	O	O	O	O	O	O
I feel confident in my ability to learn STEM	O	O	O	O	O	O
Others ask me for help in STEM	O	O	O	O	O	O
I can do well on tests/exams in STEM	O	O	O	O	O	O
I understand concepts I have studied in STEM	O	O	O	O	O	O
I can overcome setbacks in learning STEM	O	O	O	O	O	O
I am interested in learning more about STEM	O	O	O	O	O	O
I see myself as a STEM person	O	O	O	O	O	O
My family sees me as a STEM person	O	O	O	O	O	O
My friends/classmates see me as a STEM person	O	O	O	O	O	O
My classroom STEM teachers see me as a STEM person	O	O	O	O	O	O
My out-of-school teachers see me as a STEM person	O	O	O	O	O	O
I am aware of many types of STEM-related careers	O	O	O	O	O	O
I am aware of the skills STEM professionals use	O	O	O	O	O	O
I feel I belong in the STEM community	O	O	O	O	O	O

Analysis

Materialist cartography (Kuntz, 2018) supports inquiry in contexts characterized by high complexity, tension, conflicting signals, and in which the inquirer has limited sensing capabilities, and partial information. For many critical scholars, all research contexts in the social world are fairly characterized by these attributes. We feel that radical cartography requires a *methodological commitment* to certain possibilities described below, though we see no requirement for a *personal commitment* of belief in materialism's ontology as a Truth claim.

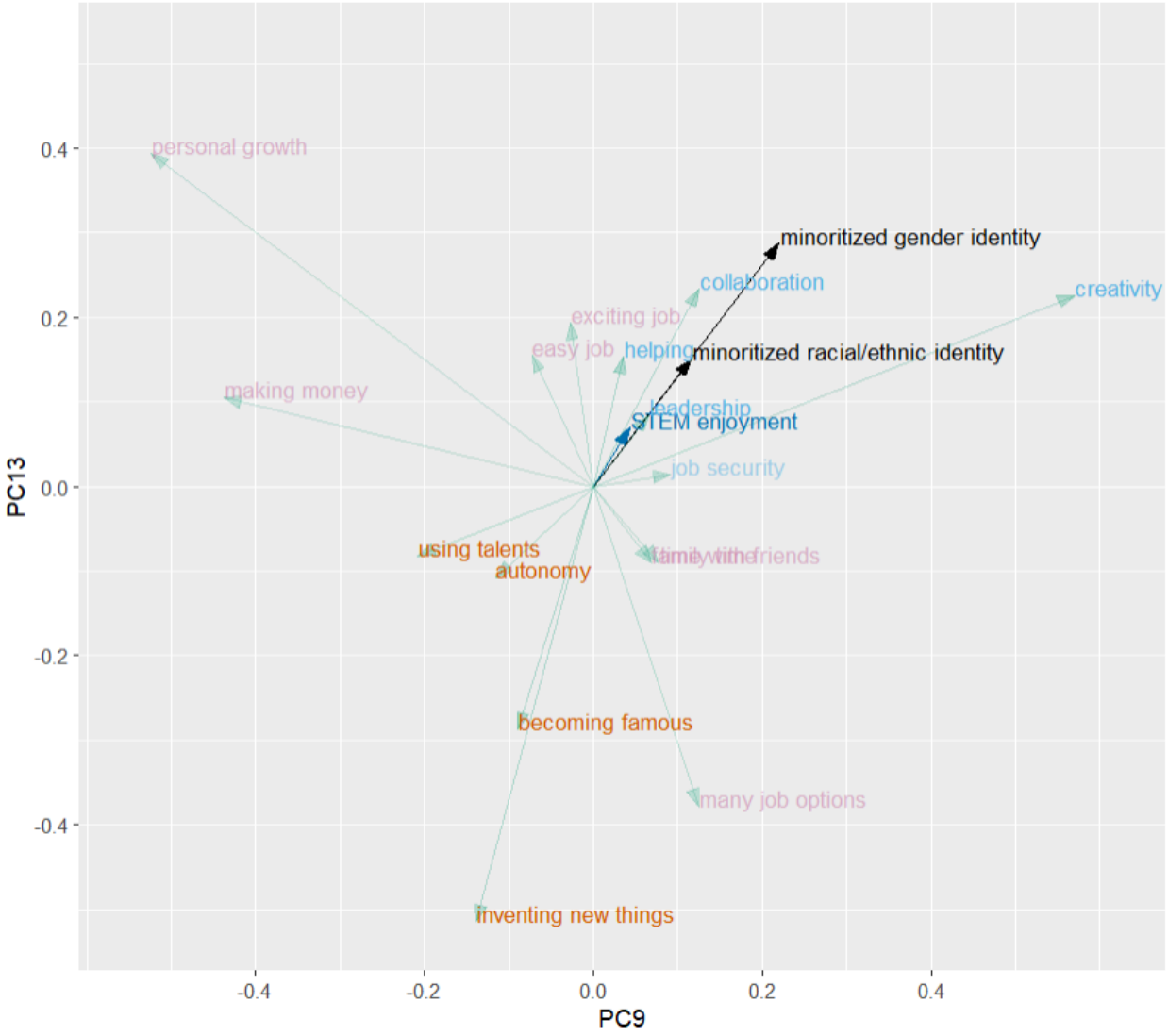
Our analysis begins with the recognition that our creative capacity to imagine alternative possibilities and theorizations is materially influenced by our present conditions. The role of relational materialism is to push inquiry and inquirers into new vantage points, outside of our sense of *the possible*, from which we may simply observe new [to us] pathways that have *the potential* to be followed. Here, we are reminded of an anecdote that, rather than pure creation from nothing, Maurice Sendak's *Where the Wild Things Are* began as "Where the Wild Horses Are." It is said that when Sendak attempted to draw horses, he could not attain any sort of likeness. What began as crude horses became a concrete material pathway to Wild Things. In similar fashion, radical cartography begins with mapping what we can discern of the present in order to identify paths to follow into new territories (Kuntz & Wooten, 2023). Accordingly, relational materialism is not a rejection of causal claims, prediction, or generalization. A methodological commitment of relational materialism, however, is to allow for the possibility that causal, predictive, and generalizable knowledge may be local rather than universal; if we inhabit new territories, they may be defined by different local logics. Because the goal and role of relational materialism is to transport us collectively into new territories, relational materialism does not ascribe value based on an ability to explain the present. The consequences for our

analysis are that there are no *a priori* metrics that establish one set of Principal Components as better than another, nor any methods of exploratory mapping that are inherently better or worse than any other. Below, we describe our particular entry point, then attempt to follow our map into a new understanding- one that exceeds the collective creative researcher imagination we had about this data prior to enacting a cartography.

Driven both by theory and empirical literature, we had previously attempted analyses on this dataset and found the resulting models lacking in statistical power, and difficult to interpret. We wanted to see what we could learn from a radical cartography with the very data that had proven stubbornly resistant to our normative quantitative analytical schemes. Collectively, the 16 career items, STEM enjoyment, and gender and racial/ethnic identity variables constituted a 19-dimensional space. We therefore generated 19 PCs to serve as the basis for our cartographic analysis. We then examined the transformation matrix to identify any PCs for which the demographic variables for minoritized identities, and STEM enjoyment pointed in the same direction (i.e. had the same sign). We refer to this set of three variables as our "orienting variables." We created the 15 possible 2-dimensional biplots of the 6 PCs that met the criterion for selection, and found that in one of the biplots (Figure 2 below), minoritized gender and racial/ethnic identities were essentially collinear, and very nearly collinear with STEM enjoyment. We then analyzed the orientations of variables in the space of the biplot to generate recommendations for teacher practice.

Figure 2

Biplot of Principal Components 9 and 13



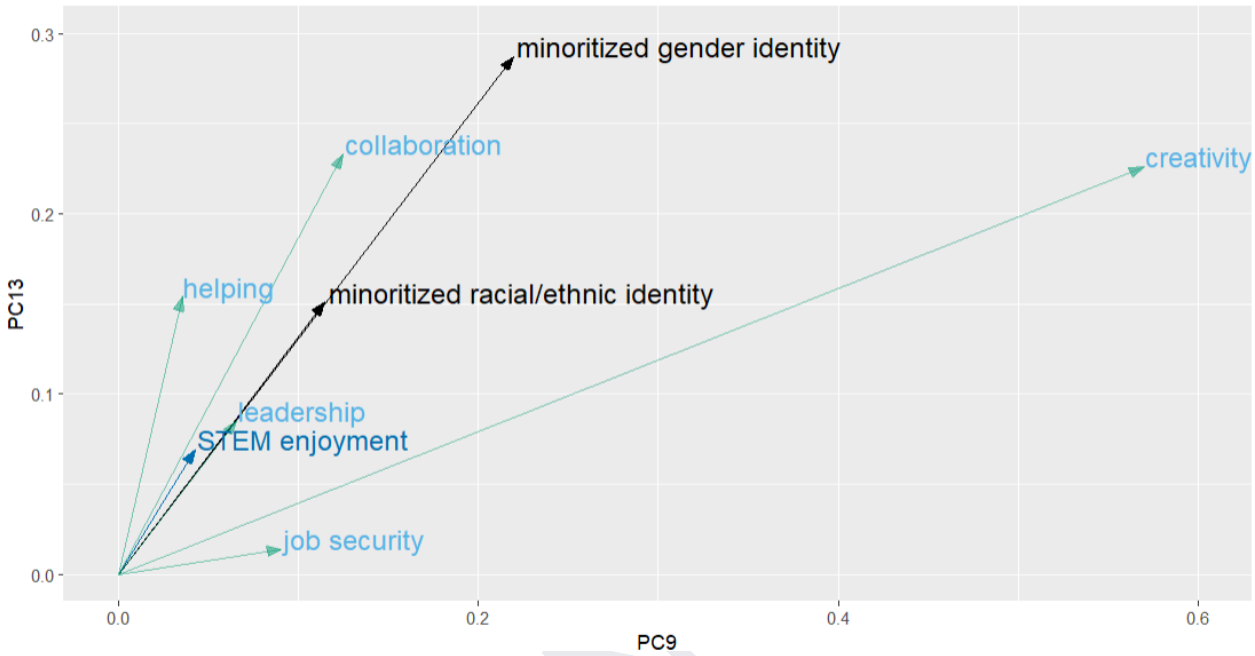
Note. When projected onto the plane defined by PC9 and PC13, the minoritized identity items (in black) are collinear, and nearly collinear with STEM enjoyment (dark blue).

Results and Conclusions

From the particular perspective of the plane defined by PC9 and PC13, we were interested in which variables in our dataset aligned with our orienting variables. Figure 3 shows the portion of the biplot that contains the three orienting variables and the 5 career covariates with positive PC9 and PC13 values. We understand these variables as potentially mutually influencing. In other words, we believe our analysis suggests that individuals who have minoritized gender and racial/ethnic identities may experience greater STEM enjoyment when STEM activities and STEM careers are more strongly connected to creativity, collaboration, helping, leadership, and job security. We found the map in Figure 3 to be immediately generative as a means to "make possible futures that were unknown [because we] hadn't mapped it" (Kuntz & Wooten, 2023, p. 85). Recalling that these data indicate first year college students' desires for their eventual careers, we are interested in the potential for science instruction that engages students in present day science learning that is characterized by the future career desires shown in Figure 3.

Figure 3

All Variables Oriented with Positive PC9 and Positive PC13 Values



We see creativity, collaboration, helping others, and leadership opportunities as especially congruent with planning activities of disciplinary science education. Although we did not anticipate this at the outset, our findings align with many reformed science teaching practices (Sawada et al., 2002). What is particularly unexpected (and very much welcome in the current environment of anti-DEI policy) is our newfound sense that something like the "good teaching" (Ladson-Billings, 1995) of project-based learning may be a radical intervention that promotes STEM identity and STEM participation of minoritized populations. Several of the authors work directly with secondary science educators across the United States. Through our Principal Components Cartography, the next time an educator asks what might be done to provide

equitable, inclusive, and justice-oriented science learning (particularly in areas where policy prohibits specific language related to identity and reference to systemic oppressions), we will reference our analysis of a large dataset drawn from the near-peers of secondary students in the following recommendation: to whatever degree possible, support students in leading one another in creative and collaborative work that orients science toward helping others.

Significance of the Study

To our knowledge, this study represents the first attempt to engage in Kuntz's relational materialist methodologies (Kuntz, 2016, 2018) using quantitative data. Accordingly, we offer this study as a proof-of-concept, not as a fixed object for replication but as a flow for other quantitative researchers to follow off of the edges of their own maps. There are no perfect datasets, but even with particularly challenging instruments, conflicting and incomplete data, we believe relational materialism provides a concrete methodological framework to leverage whatever information *is* present to aim toward different futures than we might currently imagine.

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