Problem Statement

Critical scholars have shown how quantitative inquiry often produces deficit narratives and thus can be dangerous for efforts to make society more equitable and inclusive (Arellano, 2022; Gillborn et al., 2018; Zuberi, 2001). Danger, however, need not imply incompatibility. Foucault asserted that "if everything is dangerous, then we always have something to do" (Dreyfus & Rabinow, 1983, pp. 231–232). Zuberi and Bonilla-Silva (2008) argue that one such "thing to do" is to disrupt re-inscribing logics that simultaneously inform normative social science methodologies and (sometimes invisibly) uphold an inequitable status quo. Beyond informing researchers' handling of quantitative data, re-inscribing logics also inform the design of the instruments used as the basis to collect quantitative data. Accordingly, secondary data poses a crucial question for quantitative inquiry meant to transform the status quo: how can advances in critical quantitative methodologies be meaningfully brought to bear on data whose driving questions and instruments may reinscribe oppressive social structures?

This paper explores inequity in the STEM education experiences of immigrant students in Italy, and what teaching practices might support immigrant students to value science and experience greater science confidence. Brunella and Zuanna (2011) characterize Italian society as in need of immigration to offset an aging demographic in the workforce. Despite the urgent need for immigration, many Italians are fearful of immigration (Brunello & Zuanna, 2011). Italy is home to a significant share of school-aged immigrants, approximately 25% of whom do not pursue post-secondary education (Italian Ministry of Education, 2022). As STEM careers typically require post-secondary training, lower post-secondary educational attainment hampers the future ability of student-aged immigrants to participate in many STEM-related sectors of the workforce. Immigrant students may have limited ability to participate in STEM workforce options that do not require post-secondary education, as immigrants tend to have lower science and reading performance than students who were born in Italy (Ferri et al., 2023). Using the cartographic methodologies of relational materialism (Kuntz, 2018) to inform the use of principal components generated from the TIMSS data collected in Italy in 2019 (IEA, 2020), we investigate the research question: what lower secondary science teaching strategies support Italian immigrant students' valuing of science and confidence in their science abilities?

Theoretical Perspectives

Relational materialism (Kuntz, 2018) is a research perspective that offers some suggestions as to what we might affirmatively pursue with quantitative research and its subsequent recommendations for practice. Similar to Zuberi (2001), Kuntz is deeply concerned by the potential for our resistance to systems of power and oppression to "further the very relations we seek to disrupt" (Kuntz, 2022, p. 595). 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). Relational materialist inquiry targets 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 relations within relational materialism is not undertaken to capture and define, but to map the relations of the present. From the edges of relational maps (Kuntz, 2018), 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 the context of quantitative research methods, relational materialism informs a critical quantitative "thing to do" beyond prediction or modeling to explain variance.

Methodology

As a mathematical technique, Principal Components Analysis (PCA) generates a rotation matrix that specifies the orientation of each of the principal components (PCs) in the n-dimensional space of the dataset, where n is the number of variables in the dataset. (Jolliffe, 2002). The normative use of PCA is to select a small number of PCs that explain most of the variation in the data (Harlow, 2014). In other words, PCA can generate a simplified version of a complex dataset that uses a small number of variables that preserve the overall effect of the "rules" that generated the whole dataset. From a critical social theory perspective, systems of inequity, exclusion, and xenophobia play a large role in such data generation "rules." An effect of reducing data based on "explaining variance," then, is to discard data that are not useful for portraying the social dynamics we might expect from a large study. For example, American Black women in STEM who understand their racial and gender identities as protective factors (Morton & Parsons, 2018) are unlikely predictors of a dataset that reflects a largely white population. Thus, positive experiences of STEM by individuals from minoritized groups are at risk of being interpreted as "model noise" when selecting PCs based on explanation of variance. Critically, merely generating PCs does not transform or reduce the complexity of data. Selecting particular PCs (and discarding others), however, necessarily skews our view of the data in a particular way. In this study, we make a conscious choice about how the PCs re-orient our view of the data, and to do so in a way that affirms the experiences and values of minoritized populations within STEM.

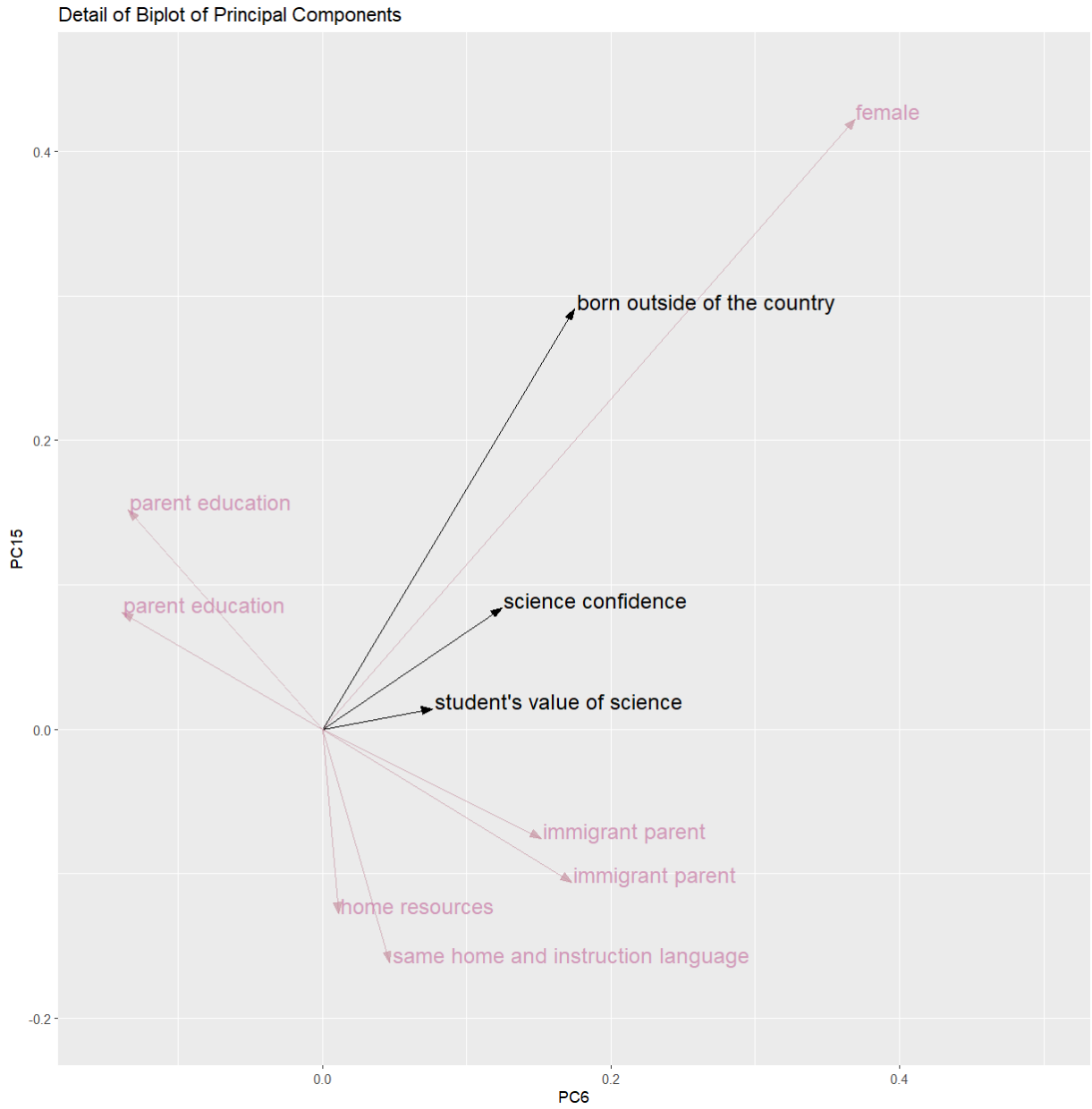
The data used in this study were drawn from the 2,032 student responses to the 2019 TIMSS Grade 8 questionnaire administered in Italy. From the 357 variables in the original dataset, we selected 48 for our analysis: 3 orienting variables for the selection of PCs (nation of birth, science confidence, and student's value of science), 7 demographic variables, 18 general affective variables that capture students attitudes and beliefs (e.g. "I like science"), and 20 specific affective variables that could be the basis for actionable teaching strategies (e.g., "my teacher links lessons to what I already know"). We generated the 48 PCs from the selected variables and conducted our analysis based on the 5 PCs along which the 3 orienting variables shared an alignment (i.e., had the same sign). We understand aligning of the orienting variables as establishing axes along which demographic and affective variables may be interpreted in relation to immigrant status, valuing of science, and science confidence. We conducted parallel analyses of all possible biplots (Greenacre, 2010) of the demographic variables and the affective variables.

Findings

Our analysis suggests multiple related but distinct student experiences of science confidence and a high student value of science, including that of female students who do not speak Italian at home and have lower home resources, lower home resources across genders and home language, and boys who speak Italian at home and have lower home resources. If we have the opportunity to present the paper, we will share each of these, along with their attendant implications for teachers' practices. Given space constraints, we will present the data that point to the values and beliefs of female students who have lower home resources and lower prevalence of Italian spoken at home. Figure 1 shows the biplot of the demographic variables on the plane of PCs 6 and 15.

Figure 1

Demographic variables in the plane of PC6 and PC15



Starting at the origin in Figure 1, and moving in the direction of greater science confidence for immigrant students aligns with the direction of female gender, leads away from greater home resources and same home and instruction language, and is roughly independent of parental education and immigration status. We interpret a biplot of PC6 and PC15 as providing information about girls from low resource households that are less likely to speak Italian at home. Figure 2 shows the affective variables plotted onto the same plane.

Figure 2
Affective variables in the plane of PC6 and PC15

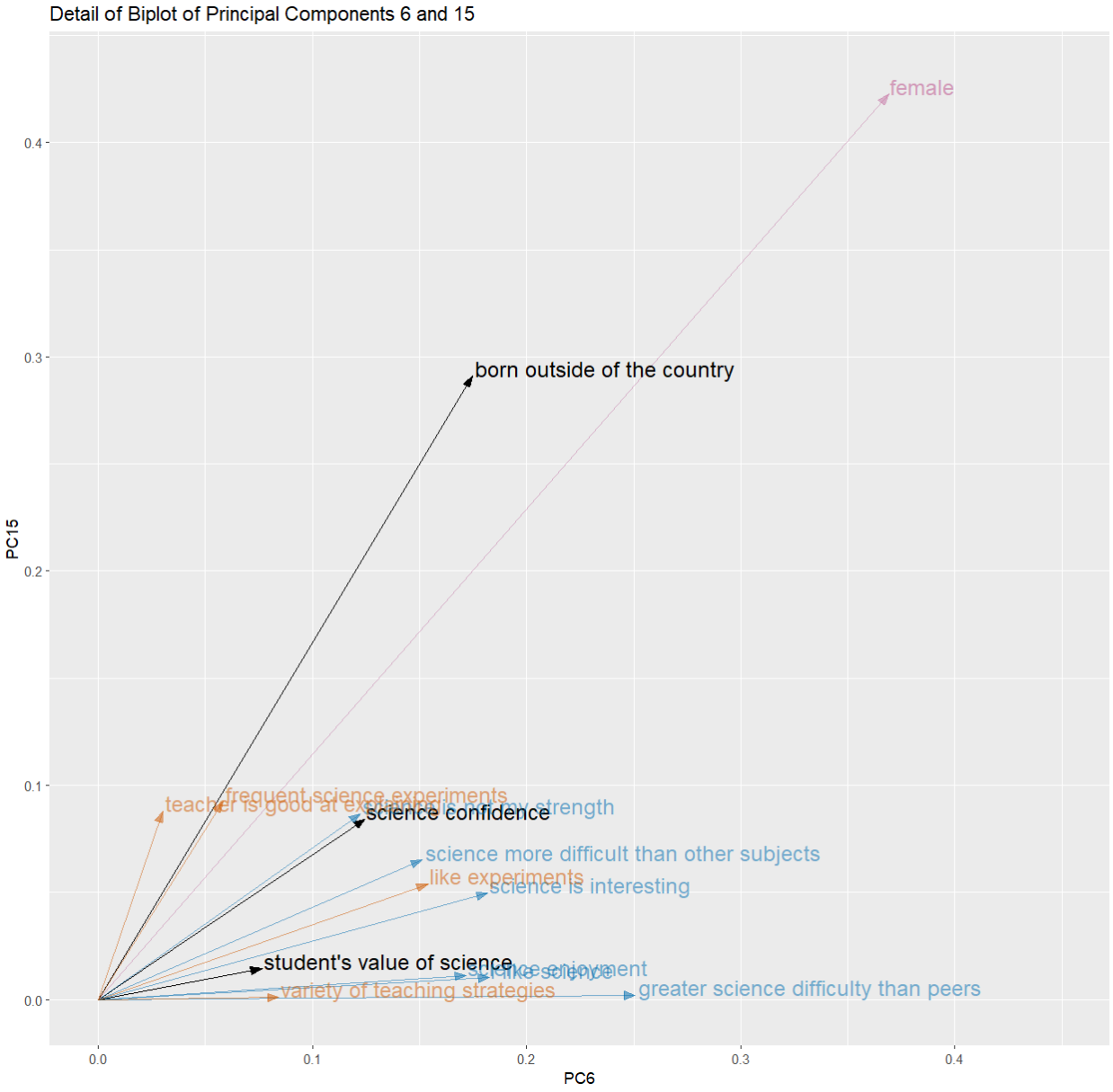
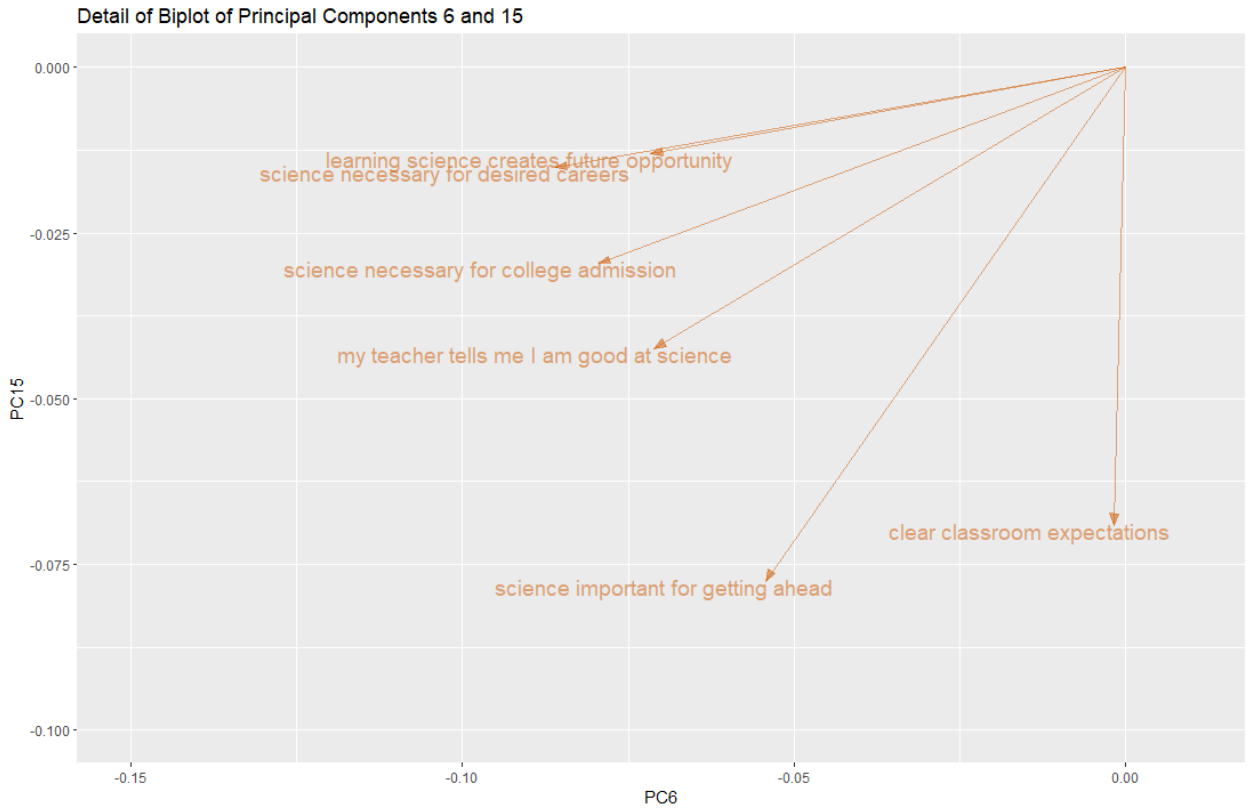


Figure 2 illustrates that immigrant girls who are confident in their science abilities and value science are more likely to report their teachers are good at explaining science, a high frequency of classroom science experiments, high enjoyment of science experiments, and that their teachers employ a variety of teaching strategies. While these are perhaps unsurprising, Figure 3 shows the specific affective variables that appear to orient away from high confidence and value of science for immigrant girls in Italy.

Figure 3
Variables in opposition with orienting variables



Given some of the literature on science identity formation (Hazari et al., 2010) and immigrant family attitudes (Langenkamp, 2019), it is somewhat surprising that higher levels of teacher recognition or classroom dialogue connecting science to careers and future opportunity are not associated with immigrant girls' science confidence and value of science. Based on our analyses, we offer what we hope is very actionable advice for supporting immigrant girls' science identities: engage students with a variety of teaching strategies, supplement teaching with multiple modes of explanation and hands-on experiments whenever possible. At least in middle grades, we believe the data support that time spent in multi-modal, hands-on engagement better supports immigrant girls' science education than connections to careers and college.

Contribution to the Teaching and Learning of Science

This paper explores the problem of connecting critical quantitative perspectives to secondary data. We used Principal Components Cartography to identify concrete teaching strategies that appear to support immigrant students to be confident in their abilities and value science within an Italian educational context. We believe this work is important, because there are many specific affective variables in the TIMSS instrument that may plausibly support immigrant students (e.g., "my teacher is easy to understand", "teachers at school are fair to me") that do not appear to support immigrant students' science education as well as a small subset that was surfaced through our analysis. These results are directly actionable by teachers who work with high immigrant populations. Given that the recommendations for practice attendant to our analysis are specific, yet flexible (e.g., "frequent science experiments"), our hope is that teachers will find them pragmatic and easy to integrate into their existing practice. Beyond merely a way to promote classroom engagement, our results suggest that multi-modal instruction may play a significant role in immigrant students' science confidence and valuing of science.

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