Research Proposal:

Beyond Gatekeeping and Obfuscation, or What Does Mathematics in Science Represent?

CU Boulder, Chancellor's Postdoctoral Fellowship for Diversity

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Often disagreement or debate within the empirical sciences are resolved by appeal to a "more precise" representational scheme. This is typically achieved by replacing qualitative descriptions with ones couched in terms of formalized, quantitative representations. There are some aspects of the physical world which are well-suited to such representations, notable among these are properties and relations called "physical quantities"—things like distance, mass, charge, velocity, spin, and volume.

Physical quantities, are commonly represented in science and everyday practice with mathematical entities, like numbers and vectors. We explain why I cannot reach the iced coffee 3ft away from me on the table by citing the fact that my arm is 2.5ft long and $2.5 < 3$. However, we don't think that the '$<$' relation between the numbers 2.5 and 3 is directly explaining anything about my arm and the coffee. Rather, this mathematical fact explains indirectly by representing some directly explanatory *physical* feature of the system *itself*. A fully explanatory account of the physical world should give us an understanding of the underlying physical structure in virtue of which these mathematical representations are successful.

My research concerns the metaphysics of physical quantities, and in particular the project of accounting for their quantitative structure in physical terms. This project is important to gaining a complete picture of the nature of the world, especially given the amount of scientific knowledge and scientific reasoning which is represented using mathematical representations. However, the project has another important set of applications, which have to do with the way that quantitative representations can be (mis-)used in philosophy and in the sciences for nefarious and gatekeeping purposes. A clear account of how the underlying facts give rise to the quantitative structures we describe with mathematics may serve to make these fields more accessible and welcoming to members of under-represented groups.

Often, the over- and mis-application of mathematical formalism and representations serve to make non-scientific, often ethically and politically nefarious, forms of investigation, medical treatments, or public interventions seem more legitimate. The works of racist eugenicists, phrenology, and I.Q. test psychology were, in part, able to operate with the veneer of scientific legitimacy and apparent rigour because their use of such formalism seemed to grant them the impersonal "objectivity" of mathematics. Even in cases of legitimate science, performed in good faith and with good intentions, mathematical representation techniques often serve as gatekeeping devices, barriers to the participation of groups historically under-served and under-represented in STEM fields.

Even within my own discipline, Philosophy, these same forces produce similarly distorted demographics. Analytic philosophy is, as a discipline, extremely white and male. It is around

75% male ("Women still receive only about 28% of philosophy PhDs in the United States, and are still only about 20% of full professors of philosophy")[1], among students receiving new Ph.D.'s in the field, the percentage that identify as non-Hispanic white are 86%. The numbers are similarly skewed towards under-representing LGBT persons. This lack of diversity sets it apart from the rest of the humanities, which have made great strides in past decades to address these problems.

The way that this diversity problem connects to my project is that the skew towards white, straight, cisgender men is even more pronounced when you consider philosophy's various subfields.

Among members of demographics under-represented in philosophy (which is to say, women, people of color, LGBT persons, etc.), there is often a general expectation that they will or ought to specialize in the "Philosophy of" themselves (which is to say, philosophy having to do with those same under-represented populations of which they are members). For example, in a comparison of the specializations of philosophers listed as part of the American Philosophical Associations "UPDirectory" (a directory of philosophers from under-represented groups), there were some significant trends in specialization that mirror this expectation. "Minorities in philosophy are more likely to work in Traditions or GRIDS+, and less likely to work in History or [Philosophy of] Math/Science"[2]

As a philosopher from a couple of underrepresented demographics, who also happens to have a strong interest in subfields like the philosophy of science, and the metaphysics of physics, I have felt this pressure first-hand. I have often had to field questions as to why I don't work on the philosophy of sexuality, or the metaphysics of gender. Apparently, the the prospect that I could be not just a queer woman but a queer *trans* woman, and not have my philosophical specialization center around philosophical issues pertaining to trans and/or queer identities, is unfathomable to some.

While some of the structural problems within Philosophy, as a discipline, are improving, many of the field's subdisciplines continue to be unaccommodating for members of under-represented groups. In many of these cases, those are often the fields which rely most heavily on formalism, and which most often assume or expect a certain amount of independent training in physics or mathematics (both fields that have similarly skewed demographics).

Part of my project will involves some investigation of how science and philosophy of science are presented to students at the graduate and undergraduate levels, and, I hope, will identify ways to change these presentations to make them more accessible and available to philosophers of all backgrounds. Wider accessibility of philosophical sub-fields and enhanced participation of under-served populations is not just a moral imperative, it will also improve research done in these fields, since it may help decrease artificial barriers keeping bright, passionate philosophers from participating.

This project has consequences for the accessibility of physical sciences to groups historically and presently under-represented in the field. When mathematical representations are employed, the mathematical structure appealed to is almost always *more* structure than the underlying

[1] Cherry and Schwitzgebel (2016) "Op Ed: Like the Oscars, Hashtag-PhilosophySoWhite" *L.A. Times*, March 2016. https://www.latimes.com/opinion/op-ed/la-oe-0306-schwitzgebel-cherry-philosophy-so-white-20160306-story.html

[2] (with "Traditions" refers primarily to feminist, non-anglophone, and/or non-European philosophical traditions, and 'GRIDS+' standing for "Philosophy of Gender, Philosophy of Race, Philosophy of Intersectionality, Philosophy of Disability, Philosophy of Sexuality"), from Higgins (2014) "Relational Mapping of Minorities in Philosophy" https://updirectory.apaonline.org/Data.cshtml

physical phenomenon being represented. That is, mathematical representations in science and philosophy of science are often employed unnecessarily, where the physical or philosophical issue being discussed can be more accurately and clearly represented without such formalism. As such, a key part of my project, is to provide an account of how we might identify the underlying structure of the world in virtue of which such formalism can be applied at all, and how those structures can be understood independently of our mathematical representations.

In my dissertation, *Physical Quantities: Mereology and Dynamics*, I defend a two-pronged account of quantity that analyzes this quantitative structure in terms of the role a given quantity plays in the physical world (how that quantity "traffics with" the rest of the physical world). Chapter 1 introduces the notion of a *properly extensive* quantity, and argues that length, temporal duration, volume, and the like are *properly* extensive, but mass and charge are not. Chapter 2 develops a theory of properly extensive quantities which defines their quantitative structure in terms of mereology (parthood structure) and shared intrinsic properties. This account captures the intuition that quantitative relations, like "longer than" or "π-times the volume of", are intrinsic to the physical systems they're called upon to explain. The second half (Chapters 3 and 4) concerns the relation between physical quantities and dynamical laws. Chapter 3 makes the case that we *cannot* apply the same mereological treatment to "merely additive" quantities (which are "extensive" but not *properly* so), like mass or charge, because their quantitative structure is not reflected in the parthood structure of their instances. That is, two massive point particles may stand in "$\sqrt{5}$-times as massive as", or "twice as massive as" or any of countless other mass metric relations, despite both having no proper parts. Chapter 4 argues that all *other* quantities (i.e. those which are not properly extensive) have their structure only derivatively, in virtue of their dynamical connections to properly extensive quantities according to the physical laws.

Excessive use of mathematical representations make topics involving quantitative properties difficult, if not impossible, for outsiders to discuss or criticize. This serves to exclude from scientific discussion members of already-underrepresented groups who are less likely to have received the same background training. The most pernicious such cases are the ones where formalism-heavy quantitative representations are not just *unnecessary* but actively obfuscatory and misleading about the underlying physical facts. Insofar as mathematical representation of quantitative physical facts contribute to this gatekeeping and exclusion, then a clearer understanding of these underlying physical facts in genuinely physical terms can form one small part of a many-pronged solution to that problem.

Currently, a key portion of Chapter 1, "Properly Extensive Quantities", of the dissertation has been published (2015, *Philosophy of Science*).. Two additional articles, consisting of material originally presented in the dissertation are currently under review. The account of quantity I present over the course of the dissertation, which uses the distinction coined in Chapter 1 to construct the two-part, hierarchical theory of quantitative structure developed and defended in Chapters 2 and 4, is well-suited to a book-length treatment. If awarded the Chancellors Postdoctoral Fellowship for Diversity, I plan to produce and submit, within the award year, a book proposal incorporating and expanding on the work I've done in the dissertation and elsewhere pursuing this project.

I am also actively working on papers that make contributions to the metaphysics of physical quantities beyond what falls within the scope of the dissertation. I expect to be in a position to complete and submit a number of these papers for publication during my year of affiliation with MSIO, if accepted. One such paper has to do with the role that quantitative conceptions of *mass* have played in historical and contemporary scientific practice.

My "Properly Extensive Quantities" (2015) introduces the notion of a "properly extensive" quantity (like length, volume, or temporal duration), and distinguish them from "merely additive quantities" (like mass and charge), which are extensive but not properly so. It has, historically, been said that mass (or extensive quantities in general) is the "measure" of a physical system's "*extent*". In this paper, "Extension, Zero magnitudes, and the Problem of Quantitative Resemblance", I argue that *properly extensive* quantities are better suited to "measure of the extent" of a physical system than the broader category of "extensive" quantities. Two important issues in the metaphysics of quantity depend, I argue, on which quantities are "measures of extent": The first concerns *quantitative resemblance*. It's generally thought that the notion of "exact similarity", understood in terms of shared natural properties, cannot account for a 3m rod being more similar a 2m rod than it is to a 45m rod (since none of them share any natural length properties except "has a length"). I argue, however, that we can give an elegant theory of quantitative resemblance, in the case of properly extensive quantities, in terms of exact similarity, but only if these quantities are the measure of a system's "extent". This account depends on the second issue, which concerns so-called "zero magnitudes". Should we interpret the terms '0m' (zero meters of length) or '0kg' as denoting a *lack* of length/mass? Or, are they merely another way of *having* length/mass, on par with any of that quantity's other magnitudes? The notion of extent, I argue, offers a clear answer: *zero extent* is a lack, while other zero magnitudes are not.

One of the papers I've started outlining most recently concerns a *specific* quantitative property and how it should be understood in relation to a particular space-time structure. It is framed around the tension between two claims: (1) In 1879, A. A. Michelson measured the speed of light to within 99% accuracy; and, (2) Strictly speaking, there is no speed of light (in special relativity). In this article, provocatively titled "There's No Speed of Light, so What the Heck did Michelson Measure?", I resolve this tension and explain how the specific value assigned to light (i.e. 299,792km/s) should be understood, if not as a speed.

While the tension between (1) and (2) is obvious, their plausibility is somewhat controversial. Many physicists and philosophers of physics reject (2). The first part of the paper resolves this confusion by diagnosing it as stemming from commitment to a "Strong Co-ordinate Abstraction Principle" (or "Strong CAP") according to which agreement between *all* different equivalent co-ordinate representations (of a given sort) about some physical claim entails that this claim is a physically real part of the system represented. This Strong CAP is *prima facie* plausible, but, I argue, this plausibility evaporates in the face of some blatant counterexamples—e.g., all the different Cartesian co-ordinatizations of a Euclidean space will all agree that "there exists some point which is the origin point" (despite disagreeing about which point it is). I argue that the problems with Strong CAP are pervasive. That is, there's no plausible weakening of CAP that could *rule out* its problem cases *and* retain the speed of light. The ascription of a speed to light is, despite its constancy across different inertial frames, an artifact of our co-ordinate system and not reflective of the physical world. Once it's established that, strictly speaking, there is no speed of light. Then the claim that Michelson measured the speed of light with upwards of 99% accuracy becomes appropriately mysterious. What could he have been measuring, if not the speed of light? Surely not something purely conventional. The remainder of the paper outlines what part of the world the value 299,792km/s corresponds to. Put roughly, the number represents an *a posteriori* relationship between our independently-chosen units for temporal duration and spatial distance. Special relativity privileges a ratio relationship between values of the two quantities which, under previous space-time theories, were incommensurable. The value obtained by Michelson is the measure of this ratio relation.