

Unpacking Social Factors in Mechanistic Reasoning (Or, Why a Wealthy Person is Not *Exactly* Like a Grey Squirrel)

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Abstract: Mechanistic reasoning in social domains is understudied. We speculate that the ways that students reason about social phenomena share enough similarities with how they reason about physical and life sciences that we can use existing work on mechanistic reasoning to characterize students' explanations of social phenomena. We apply an existing framework for analyzing student reasoning about life sciences to students' explanations of a social phenomenon relating to urban planning. In comparing these analyses, we propose a component of student reasoning that may be specific to reasoning about social phenomena: social factor backing. We show that incorporating this component into the existing framework provides a fuller account of our data. Finally, we discuss why we think this element could be important for future studies of students' mechanistic reasoning about social phenomena.

Keywords: mechanistic reasoning, science education, social science education

Introduction

Mechanistic reasoning, or reasoning systematically through how and why underlying factors and relationships give rise to a phenomenon (Machamer, Darden, & Craver, 2000), is a valuable form of human thinking. It allows people to systematically explain and predict events in contexts as wide-ranging as workplace and organizational dynamics (e.g., Senge & Sterman, 1992), traffic jams (e.g., Wilensky & Resnick, 1999) or fluctuations of populations in ecosystems (e.g., Jacobson & Wilensky, 2006). This type of reasoning is increasingly becoming a focus of schooling across disciplines. In particular, science education reforms such as the Next Generation Science Standards call for integrating causal, mechanistic thinking as a crosscutting concept in science instruction (NGSS Lead States, 2013). Along a similar vein, the NCSS recently released The College, Career, and Civic Life (C3) Framework for Social Studies State Standards (NCSS, 2013), proposing new K-12 social studies in which they emphasize 'complex causal reasoning'. Although we have some ideas about what mechanistic reasoning looks like and how to support it in science classrooms (e.g., Russ et al., 2008; Schwarz et al., 2009), research has strikingly tended to separate out reasoning involving people as "social" or "socio-cultural" reasoning that is distinct from—or even in opposition to—"scientific" reasoning based in logic and mechanism (e.g., Lee, 2012; Pedrett & Nazir, 2011). As such, we know very little about what mechanistic reasoning looks like in contexts that include people as humanized components of systems, or how students' reasoning about those mechanisms compares to mechanistic reasoning about natural phenomena (i.e., not involving humans). As we work to prepare students to solve complex, multifaceted problems in a world where the social and natural spheres are intimately interconnected, we need to better understand what mechanistic reasoning is and what it involves in order to design curricula and instruction that better supports students in this kind of crosscutting mechanistic reasoning. Here, we aim to characterize students' mechanistic accounts of natural and social phenomena using the same framework in order to identify similarities and differences that contribute to a general theoretical model for mechanistic reasoning and suggest important analytical differences that can help bridge our understanding of mechanism from the natural sciences to the social sciences.

What is a mechanism in the natural sciences? In a synthesis of work from the philosophy of science, Machamer, Darden, and Craver (2000) define a mechanism as: "entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions" (p. 3). Russ et al. (2008) apply this definition to identify elements mechanistic reasoning in student discourse, including identifying entities, or "the things that play roles in producing the phenomenon" (p. 14); and a set of elements that together are about "characterizing entities": identifying activities, properties, and/or organization of those entities. For example, a student seeking to explain how and why they could smell popcorn inside their classroom when it was being popped in the teacher's lounge could identify that both the popcorn odor and the air are made of *molecules* that are constantly moving and bouncing off each other. They might also reason that the popcorn odor molecules are warmer than the air molecules and therefore have more energy. Though not yet a full causal account, this activity of identifying and characterizing the entities involved in producing a phenomenon are a critical part of reasoning through a mechanism.

However, the nature of the entities that students characterize, and subsequently use to reason with, may differ across science contexts. In the physical sciences these entities are often individual agents like molecules. But in the life and earth sciences the units that students identify and reason with are more often *relationships* between entities, properties, and behaviors, such as “grey squirrels can eat acorns” (Krist, Schwarz, & Reiser, under review). It is these relationships that are most productive for students to think with as they account for phenomena occurring in complex environments such as an ecosystems (c.f., Vattam et al., 2011). We follow Author 2 et al., and use the term “factor” to describe the unit that students identify and subsequently use to reason, whether that factor be an individual agent or a relationship. Due to these observed variations in science contexts, we wondered if we would see new types of factors and reasoning about social phenomena. Because social phenomena often involve values and decisions, we speculated that the way students identify and characterize factors in this domain may have additional dimensions related to human decision-making.

In this paper, we seek to explore *the nature of the factors that students identify* and *how they characterize them* as they construct mechanistic accounts of social science phenomena. We do so by analyzing college students’ responses to a question about the relationship between income and commute times. Our preliminary analyses show that students do in fact identify and unpack factors as an important part of their mechanistic reasoning. However, students also reason through how the entities in the system (people) make decisions that as part of their explanation of the phenomenon. We discuss how this affects both our theoretical understanding of mechanistic reasoning more generally and how we can better support students’ use of this dimension in their mechanistic reasoning across domains.

Methods

To examine elements of students’ mechanistic reasoning in a social science context, we used written responses from undergraduate students during a unit on urban planning. During the unit, students interacted with a NetLogo (Wilensky, 1999) model that allowed them to build a city by drawing in various types of zones (residential, industrial, etc.) and constructing major highways and public transit lines. While running the model, they could monitor several variables, including average commute time, average income, and distribution of income levels across the city. After the unit, we gave students a post-test that included the question, “Can you explain how a high-income person’s income might make their commute time longer than a low-income person’s?” Students wrote short answer responses that were between 1 and 4 sentences long.

To analyze these data, we utilized Krist et al.’s framework for differentiating the relative complexities of students’ mechanistic accounts. We draw on their notion of a “factor” as whatever unit students identified and used to reason through a phenomenon. We speculated that students would likely identify complex factors, such as entity-property relationships. We also noted where students “unpacked” those factors, or reasoned through how the implications of those relationships over space and/or time gave rise to the observed phenomenon (Krist et al., under review). We highlight four student responses that exhibited varying levels of mechanistic reasoning in order to show contrasting cases (Table 1). In the following section, we account for our analysis of these four responses, discuss similarities and differences between the two datasets, and articulate the degree to which the analytical framework can help us make sense of them.

Findings

In the first response, SS1 identifies two factors; that low-income people live in the city, and that wealthy people live in more spread out suburbs. However, while both of these factors are important parts of a full explanation, SS1 does not unpack and say *why* these two factors would lead to differences in commute times for the two population groups. In the second response, we see that SS2 identifies two factors as well. One is the same as SS1, and the other is different: that higher income people typically live in suburbs, and that they work downtown. Additionally, this student unpacks the relationship between these two factors, and explains that the reason why higher income people have higher commute times is that these two factors combined lead to *longer drives*. Finally, there is a probabilistic element in SS2’s explicitly says that high income people *typically* live in the suburbs. We see this response as similar to a response to the life sciences question in which a student claims that red squirrels *typically* cannot eat acorns (though it is always possible that some of them might have randomly mutated in a way that allows them to do so). So far so good, and we can see that applying Author 2 et al.’s framework helps us identify elements in student responses.

However, we see something different in SS3’s response that we think might be related to the probabilistic element in SS2’s response. SS3 identifies the same two factors as SS2 (that wealthy people can live in suburbs, and that they might work downtown), but goes on to explain that wealthy people *‘are able to afford’* living in suburbs. We feel that this is an important part of the reasoning, but we struggle with classifying it under the existing framework: it is not exactly a factor in itself, because it cannot be unpacked on its own or even with other

factors. It would not, for instance, be convincing or good mechanistic reasoning to say, “People can afford to live in suburbs, therefore they have longer commute times” (although some students did say that.) Rather, stating that wealthy people ‘are able to afford’ living certain places seems to offer a justification or backing to the ‘wealthy people might live in suburbs’ factor by explaining why, for some members of this population, this factor exists. In other words, where the color of a squirrel has a probabilistic effect on what the squirrel can do, the wealth of a person has a probabilistic interaction with what that person *chooses* to do.

Table 1: Four responses to the prompt about urban planning

Poor people live in dense industrial centers, while wealthy people live in more spread out suburbs. (SS1)	They typically live in the suburbs and work downtown so <i>they have longer drives for commute times.</i> (SS2)	A wealthy person's income can make their commute time longer if <i>they live farther away from their jobs.</i> For example, some wealthy individuals live in suburbs, but their jobs are in industrial cities. Because they have a higher income, they are able to afford living in these communities, but their commute time is longer than a poor person who happens to live near industrial areas. (SS3)	A wealthy person's income could make their commute time longer because they can afford a car, which means <i>they could get stuck in traffic.</i> They also have the ability to choose where they live based on safety, quality schools, lots of parks, etc - and the <i>place that fulfills all of these requirements might be far from work.</i> (SS4)
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This is even more evident in SS4’s response: Similar to SS3, SS4 connects wealthy people’s wealth to their ‘ability to choose where they live’. However, SS4 goes on to list potential wants and desires in wealthy people that could lead them to make a particular choice: ‘*safety, quality schools, lots of parks, etc.*’ Finally, SS4 gives the underlying factor that actually answers the question: they might choose to live in a place that is ‘far from work.’ However, in order to get to this factor, they had to reason through what they assume that people want, and under what conditions people might (or might not) do that.

We believe that this process of reasoning through the conditions and probabilities of human choice is a distinct, and important part of mechanistic reasoning about social issues. In order to fully analyze and assess students’ mechanistic reasoning about social issues, we therefore suggest that it is necessary to add an extra step to Author 2 et al.’s analytical framework: a process of backing or defending the factor identified, based on the choices that entities have in capacity of their property, and of considerations of the wants and desires that led them to make choices that resulted in the factor. We call this process “social factor backing.” We propose that this process consists of:

- identifying a factor, such as “wealthy people tend to live in suburbs,” that contains an entity and at least one of the defining properties of the entity (e.g., a person + wealthy);
- recognizing that that factor (that wealthy people live in suburbs) comes out of the relationship between entity and property (e.g., wealthy people can afford to live in suburbs *because* they are wealthy), not because of random arrangement or assignment of natural factors;
- walking through the rationale of the entity for making *that particular* decision (and not any of the other possible decisions) by connecting its decision to assumptions about the entity’s underlying wants and desires (e.g., wealthy people want to live near parks and good schools, and can afford to do so); which leads to:
- the statement of the factor, which has now been backed (e.g., therefore some wealthy people live in suburbs). This factor can then be unpacked as normal.

The additional step to Author 2 et al.’s framework is step b) in which students explicitly reason through what it is about the entity + property relationship that provides choice(s), and in c) in which the student account for the particular wants and needs in the entity that led to making that decision. Revisiting SS2 with this new construct, we can now more clearly begin to see where this response is lacking with regards to mechanistic reasoning: SS2 correctly identified the two factors (wealthy people live in suburbs, and they work in cities), and unpacked them (‘so they have longer drives’). But SS2’s response neither states that they live there because their wealth allows them to (b) or that they live there because they *chose* to (c). So while the overall claim in the explanation is true, we think that it fails to capture some fundamental, and to us, important underlying *social mechanistic* reasons: that people do things for different reasons because of the complex interplay between their inner wants and desires, and choices afforded to them by their properties.

Implications and conclusion

In this paper, we showed that it can be productive to use mechanistic reasoning to understand students' reasoning about a social phenomenon. It helped us identify which factors that students reasoned about when they explained the phenomenon, and it helped us structure an analysis of how these factors taken together caused the phenomenon to occur. However, the existing framework we used did not allow us to fully capture the kind of reasoning that students did about how entities have a range of options because of something inherent in them, and how they then reasoned about the decision making process. By adding 'social factors backing', we were able to more fully account for this part of their reasoning. We believe that this could be an important component of reasoning mechanistically about social phenomena, and that a consideration to the choice- and options-elements may be important in the study of, and design for learning activities about, social mechanisms.

Our treatment of students' reasoning did not consider the important connection between language and ideology (Fairclough, 1995, 2003; van Dijk 1998), and treated the use of 'poor' as equal to 'low-income'. Lexicalizations like these may express important difference in reasoning, in particular relating to social factors, like the wants and needs of social actors. Student responses also implied that certain outcomes were more desirable than others, but these aspects of thinking were ignored for the purpose of this analysis. Future work should include considerations to these value-laden aspects of language use.

The C3 framework's focus on 'complex causal reasoning' suggests an increasing focus on reasoning in social sciences education at the K-12 level. Research in science education has for decades improved our understanding of what causal reasoning about the natural sciences looks like. The early findings in this paper suggest that mechanistic reasoning can be a productive lens on students' reasoning in social sciences. Future work will aim to improve our understanding of social mechanistic reasoning with an eye towards the larger educational goals: building curriculum to support and develop this kind of mechanistic reasoning; exploring this with different social phenomena, and building meaningful assessments of student learning.

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