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The cognitive labour of mathematics dis/ability: Neurocognitive approaches to number sense

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ABSTRACT

In this paper we discuss neurocognitive research into number sense to show how it reconfigures the cognitive labour of the mathematics student. Neurocognitive research is redefining mathematical proficiency and student agency in terms of the activation of "neuronal populations". We show how this research deploys a particular image of number that stresses cardinality rather than ordinality. An emphasis on cardinality effectively reduces the time-value of students' cognitive labour, produces new kinds of dis/abled bodies, and recruits new kinds of value from those bodies. We discuss current research on dyscalculia in mathematics education, and situate this work in relation to literature in critical dis/ability studies and inclusive materialism. We suggest that the concept of 'student alienation' must be radically reconfigured in contemporary contexts in order to address the biopolitics of current education research. Our aim is to direct attention to the need for new kinds of neurocognitive research, not to reject it altogether.

1. Introduction

In this paper we discuss neurocognitive research into number sense to show how it reconfigures the cognitive labour of the mathematics student. We use the term 'labour' in order to situate our work in relation to theories of capitalist labour and alienation. In Marx's early work, alienation identified facets of *industrial* labour that were dehumanizing and destructive of both the individual and the collective (Geyer & Schweitzer, 1976).[1] The mechanized factory labour of the industrial revolution alienated the worker from himself and his co-workers, from the product of his labour, and from labour itself. Marxist theories of alienation have since evolved in an attempt to incorporate other kinds of unpaid labour—for example, the labour of the housewife and student. Sociological studies of education, for instance, have tracked the cultural and symbolic capital of student labour. Williams (in press) writes "substitute grades for wages, learning for labour, schools for factories, teachers and headteachers for managers, the state for the owners of factories, and you have alienation of learners from learning, and from teachers, in schooling (see also Engestrom, 1987, 1991)" (p. tba). In other words, learning is an *intellectual* labour, and can thus be studied for how it incorporates and is incorporated into capitalism.

More recently, the term "cognitive labour" has been introduced to address new developments in contemporary capitalism. Cognitive labour refers to the distinctive forms of contemporary labour that emphasize knowledge, information, affect and communication, and that are characterized by a new phase of digital technologies and internet-based economies

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[1] The term alienation was used by other philosophers, such as Rousseau and Hegel, prior to becoming part of Marxist terminology.

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(Peters & Bulut, 2011). This kind of labour is "cognitive" because it de-emphasizes manual or physical skills – except for typing and viewing – while emphasizing the *distributed cognition* of communication networks and the production of "immaterial" products, such as information. Berardi (2009) suggests we use the term "semiocapital" to describe the cybernetic substitution of information for material objects, and that we focus on the "endless cognitive stress" that the individual undergoes in digital times. Since students participate in this cognitive labour, they are named part of "the cognitariat", and are themselves a "semiotic labor flow" (p. 105). We see in this theoretical shift, an attempt to track new convolutions of capital and labour that radically reconfigure what it might mean *to labour* and what it might mean to be alienated from one's labour.

Alongside this development, and historically linked to it through the cybernetic movement, has been an increase in neurocognitive approaches to the study of mathematical dis/ability and number sense (Dehaene, 2011). Neurocognitive research into "number sense" began in earnest in the 1950s and 1960s exploring animal, infant and trauma victims' ability to perform tasks that entailed some sort of quantitative discernment (Mechner, 1958). With the advent of brain imaging technology, cognitive neuroscientists have shown that a particular group of neurons in the brain – in the intraparietal sulcus (IPS) – are always "activated" whenever humans, and many other animals, are given a calculation task (see Bugden & Ansari, 2015; Neider & Dehaene, 2009). These scientists are searching for the "number neuron" where they believe number sense resides. Such research has popular appeal, and is taken up in the press often without any critical reflection (de Freitas, 2014). The impact of this research on education is potentially profound, as many dis/ability theorists cite it as evidence that number sense is biologically innate (see, for instance, most of the thirty-one chapters of the *Routledge International Handbook of Dyscalculia and Mathematics Learning Difficulties* (Chinn, 2015)).

In this paper, we show how this research is re-configuring number sense as a kind of *neuro-cognitive labour* that mirrors computational informatics. We track the way the student body is recruited in such cognitive labour, indeed how the human organism is reconfigured so that the concept of *human* capital becomes *neuro-cognitive* capital. By focusing on the neurocognitive research on number sense, we aim to show how biopolitics infiltrates cognitive labour, where value is extracted from the labour of the neuron. Through these research practices, the human body is tapped in new ways; the body is retrained to produce new kinds of value: "What is at stake within the social definition of cognitive labour is precisely the body, sexuality, mortal physicality, the unconscious" (Berardi, 2009, p. 106).

We examine recent cognitive neuroscience on dyscalculia that claims to identify the biological source of number sense, and we argue that this research rests on tacit assumptions about the nature of number, with implications for how we understand cognitive labour. The experiments that are typically used in this research depend on automatic, near-instantaneous participant responses, which are more suitable for judgements of cardinality than of ordinality (Lyons & Beilock, 2011). Similarly, theories of 'number neuron' activation present an image of number that is almost exclusively cardinal. We argue that this bias towards the cardinality of number is a significant biopolitical issue because of the way it mobilizes the cognitive labour of children. Ordinality has a significant *temporal* dimension because counting unfolds in time, unlike semi-instantaneous judgements of the cardinality of sets. Indeed, number becomes a temporal event *through* ordinality, and we argue that this temporal dimension of number is crucial for reclaiming the labour involved in computation. In other words, we aim to show how the concepts of labour and alienation are newly inflected by current neurocognitive approaches that effectively *deny* the ordinality of number, and thereby *deny* the time-value of cognitive labour. Thus our argument operates at two levels: on the one level, we show how this kind of research produces dis/ability in human bodies through its image of what constitutes number sense, and on the other level, we show how this research assumes that cardinality is the fundamental function of number. This dual focus allows us to show how mathematics *itself* is strongly linked to historical embodied practices, and that particular images of number are validated through particular kinds of research and policy.

This paper raises questions that are urgent in the wake of the increasing reliance on brain research in education: How does this new research change what it means to know mathematics? Where is the agency of the student when we turn to neuronal activation? And how is value being extracted from the body through these tests of numerosity? Our aim is to direct attention to the need for new kinds of neurocognitive research, not to reject it altogether. In this, we follow Fitzgerald and Callard (2015) who urge social scientists to engage with the experimental practices of the neurobiological, to take up and consider these practices in detail, so that a more open ethos of experimentation might be pursued as we grapple with the entanglement of "sociocultural webs and neurobiological architecture" (p. 3). This paper contributes to efforts in rethinking the relationship between sociocultural and neurocognitive work, examining the specific experimental practices that are being used to forge a new image of 'biosocial' life.

2. Dis/abled bodies

We begin with the assumption that education operates through the student body, and that particular kinds of bodies are produced and sustained through education. As Goodley (2009) suggests, "educational institutions and discourses require (children's) bodies to be measurable, accessible, easily treatable and understood. Bodies that morph in ways that are unintelligible – that are not dis/abled enough or fit the typology of dis/abled used by educational institutions – are not easily included" (p. 264).

We situate our work within an inclusive materialist approach to the study of mathematics education (de Freitas & Sinclair, 2014a, 2014b). Inclusive materialism maps the diverse materialities at work in school mathematics, with particular attention to the ways in which bodies are assembled as a form of biopower. Rather than simply treat the body as the inert matter onto which culture projects images and identities, we emphasize the non-discursive material force of bodies. Attention to the force and potentiality of the body helps us study the lived experience of mathematics students in new ways, allowing us to rethink the nature of student alienation. In addition, attention to the ways in which bodies are taken to be different or deficient helps us better understand how abled bodies are produced out of certain material-discursive practices.

Debates about the existence, definition and identification of disabilities continue in the education literature. Borgioli (2008) distinguishes between a modernist (medical) approach to dis/ability, which assigned the source of dis/ability within the individual, and a postmodernist approach that views "disability as a social construction based on incorrect, immoral assumptions regarding difference" (Hallahan & Mock, 2006, p. 27). The 2004 U.S. *Individuals with Disabilities Act* (IDEA) seems to favour the former approach, as it explicitly defines disability as a disorder *within* the individual. In the 1990s, there was concern that the "postmodernist" focus on the discursive production of identity tended to deny or demote the visceral and tactile experiences of the disabled (Patterson & Hughes, 1999; Linton, 1998).

The political terrain of *learning dis/ability* has recently been influenced by the neurodiversity movement, advocating for the right to cognitive difference while resisting others' claims that such differences need to be corrected. Recent research on dyslexia, for instance, celebrates the exceptional spatial reasoning of dyslexics rather than dwelling on the difficulties they experience with the alphanumeric (Eide & Eide, 2011). People diagnosed with dyslexia may struggle with procedural learning and rote memory tasks, but their memory of phenomenological details – that is, details pertaining to physical aspects of an experience, such as tactile, motor or spatial arrangements – exceed that of non-dyslexics (Eide & Eide, 2011).

The 'dyscalculia' label provides an interesting case study, because of its rapid take-up in both research and popular literature on learning dis/abilities (Gifford, 2006). In Section 3, we examine the research literature on dyscalculia for how it produces biomarkers of dis/ability and contributes to the biopolitical framing of school mathematics. We discuss in some detail the tasks that are used to identify students with developmental dyscalculia (DD),[2] and the underlying conception of number that they assume. Our purpose in examining these research practices in detail is to expose the ways in which tacit assumptions about the nature of number underpin a new way of thinking about cognitive labour and dis/ability in the field. Later in the paper, we return to the question of the body in light of this research, and we revisit the biopolitics of dis/ability through the work of Deleuze and Guattari (1987).

3. Number sense and dyscalculia

Popularised by Dehaene's (1997) book *The Number Sense*, in which the term 'number sense' referred to the "sense of approximate numerical magnitudes", it is now used much more broadly as a catchall phrase for describing arithmetic skills, particularly in the pre-k to grade 2 curriculum (e.g. NCTM, 2014). Dehaene (2011) traces early attempts to study human number sense to 1886 when the American psychologist James McKeen Cattel designed an experiment to test participant's response time during tasks of enumerating the number of black dots on a series of cards. Alternative methods for accurately measuring the time required to quantify sets of objects were developed in the early twentieth century, with the aim of studying how humans can enumerate *without counting*, which is known as "subitization".[3] These experiments demand that the participant announce or somehow indicate the visible quantity. Although response time is a fraction of a second for one, two and three dots, it increases linearly with each dot added up to six. Researchers began proposing cognitive models to explain these kinds of findings. For researchers in neuroscience, the term *number sense* gets operationalized much more specifically, as they focus more narrowly on *neurological* changes correlating to particular kinds of numerical tasks, and yet the tasks are the same. Nieder and Miller (2003), for instance, identified the individual "number neuron" in rhesus monkeys by presenting the monkeys with pairs of slides containing dots on them that varied in size, shape or numerosity. They then identified the neurons that responded *only* to changes in numerosity. This approach to number sense is now being used in the study of dyscalculia.

Developmental dyscalculia (DD) is said to affect 3.6–6.5% of "individuals", with the range depending on the particular experiment used, each differing in sample size and test instruments (Butterworth, 2005). It has been defined as a "learning disorder" that "affects the ability to acquire school level arithmetic skills" (Price & Ansari, 2011, p. 1). Debates regarding the extent to which DD is related to environmental context have led some scholars to distinguish between primary and secondary developmental dyscalculia (Emerson & Babtie, 2015; Kaufmann et al., 2013). These debates concern attempts to locate the exact cause of dyscalculia in the brain, and have spawned theories about how or whether DD is related to working memory, inhibition control, or perceptual skills. As Gifford and Rockliffe (2008) point out, the plethora of diverse definitions of dyscalculia makes the concept vague and open to misuse. Dyscalculia has been included in the *Diagnostic and statistical Manual of Mental Disorders* DSM 5 (2013), which is used across the world to diagnose and identify problems with "number sense", as "patterns of difficulties characterized by problems with processing numerical information, learning arithmetic facts, and performing accurate or fluid calculation" (APA, 2013, p. 67). This DSM definition is pivotal in how it shifts the focus

[2] The term 'developmental dyscalculia' refers to dyscalculia that begins in childhood and is not the result of a particular medical condition or injury.

[3] Subitus is latin for sudden. Interestingly, it typically takes people the same amount of time to indicate one or two dots, and a little longer to subitize three dots, about five to six tenths of a second.

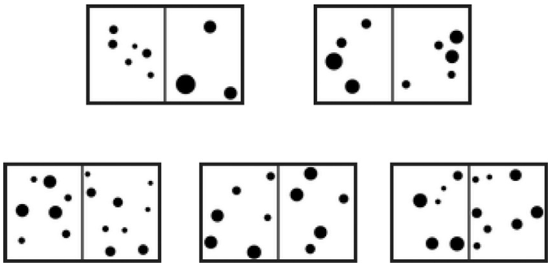

Fig. 1. Sample dot comparison tasks from Ansari tests.

to the cognitive labour of "processing numerical information", using the language of computational informatics to describe human number sense.

In line with the tradition of early experiments with subitizing dots, assessments of dyscalculia tend to focus on skills at estimating and comparing quantities of small sets of items *without counting*. In Section 4, we discuss in detail the kinds of tests that are used to assess dyscalculia and how subitizing skills have come to characterize number sense. We show how *set theoretic* notions of cardinality and ordinality dominate the image of number that is mobilized in research on dyscalculia, with direct implications for how students' dis/abled bodies are produced.

4. Overemphasis of cardinality

Nieder and Dehaene (2009) identify two fundamental numerical concepts associated with number sense: the first is *numerical quantity* (the cardinality of a set) and the second is *numerical rank* (the serial order of elements in a set). These correspond to set theoretic distinctions between cardinality and ordinality. As was the case with the early experimental investigations into number sense discussed above, the focus on subitizing emphasizes the cardinality concept. Reigosa-Crespo and Castro, (2015), for instance, focus on *magnitude processing* of numbers in symbolic and non-symbolic formats and describe "numerical magnitude" exclusively as cardinality: "To grasp the magnitude concept we need to learn the distinction between the transformations that do or do not modify the cardinality of a set (e.g. adding or removing objects in a set modifies the cardinality; spreading or grouping objects does not). We also need to compare between the numerosity of different sets (e.g. set A could be smaller, larger or equal to set B)" (p. 60). Indeed, the standard test for assessing dyscalculia consists of comparison tasks using dots (non-symbolic magnitudes) and digits or numerals (symbolic magnitudes) (see Figs. 1 and 2). Test takers are shown two side-by-side images with a line separating them, and asked to quickly identify which image has more dots, or which side has the greater numeral, or they are asked variations of such a question. It is important to look carefully at these tasks because they play an integral role in defining what counts as normal number sense, and in turn dyscalculia.

Success on these tasks is measured in terms of reaction time (RT). The research with these tests has consistently showed that RT is longer when the numerals are less different (2 and 9, versus 2 and 4), and that this is true for both symbolic and non-symbolic settings (numerals or dots). Just as it is easier to compare two very different weights or sound levels, people find it easier to identify which numeral is larger if they are extremely different. The nature of this cognitive labour depends on which theory is being used; some describe it as a mental construct of an internal number line while others refer to some arrangement and degree of neural activation. These theories, which posit an "approximate number system" (ANS), assume that people (even infants) and some non-human animals have an innate capacity to detect cardinalities (see Dehaene, 1997).

However, as Rips (2015) points out, it is difficult to see how comparing two masses (a feather and a litre of milk), whose weight can be felt, or two spatial areas, whose size can be seen, is necessarily so different from the dot task. One simply makes a perceptual judgement, which is easier to make the greater the difference between the two *sensations*. This would call into question the existence of an isolated cognitive numerical ANS that is not simply part of a more cohesive perceptual system of judgement. Further, there are many ways in which we use numbers in everyday life that do not depend on cardinality, such as turning the dial to the radio station, finding the right seat in the theatre and turning to a specific page in a book.

Current approaches to number sense state that ANS enables the later development of ordinal relations, privileging cardinality as the more fundamental in mathematical cognition (Coles, 2014). As a way of addressing the over-emphasis on cardinality, Lyons and Beilock (2011) devised an ordinal task in which sequences of three numbers (or three sets of dots) were shown to participants, who then had to decide whether they were correctly ordered (either ascending or descending) or not. For example, the sequences [2, 3, 4] and [4, 3, 2] are correctly ordered but the sequence [2, 4, 3] is not.[4] The researchers compared "close" sequences, in which the numerals were consecutive, with "far" ones in which the difference between the

[4] Lyons and Beilock (2011) argue that this task differs from previous ones that aimed to study ordinality where two numerals were given and participants were asked whether one arrived earlier/later than the other or whether the numbers were in ascending or descending order, because these tasks actually required an initial judgment about cardinality.

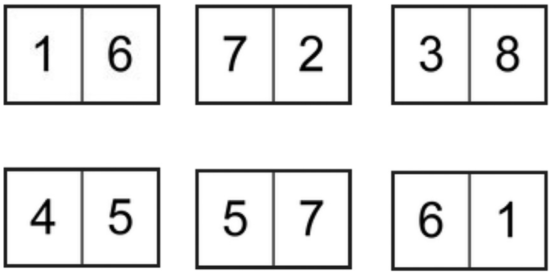

Fig. 2. Sample symbolic comparison tests from Ansari tests.

numerals was two or greater. Although the dots task showed the same distance effect as has been found using the cardinal task, the numerals showed the reverse; that is, close triplets were more quickly and correctly identified as in or out of order than triplets with large differences between the terms. For example, 14, 3, 5 required less response time than 7, 3, 5.

Lyons and Beilock (2011) argue that this experiment shows how the meaning of a numeral is relational, strongly tied to the unfolding of the *sequence* of numerals. According to Lyons and Beilock, the ordinal task calls upon the rote connections that we form in reciting the “number song”. This hypothesis seems to support Seidenberg’s (1962) theory of the ritual origins of counting, in which the recitation of the count list long precedes, sociologically speaking, the more cardinal counting of things (animals, people, money, etc.). Seidenberg argued that acts of ordinal counting are principally about calling forth the next or an(other), making the new or next appear, and not just about ordering that which is already visible. This emphasizes the temporality of ordinality, how it unfolds in time, how it indexes the sequence of numbers whatever they are, and how it brings forth the new. Rather than timeless cardinal numbers that are either “processed” by brains or not, a more robust approach to the embodied experience of ordinality brings time back into number. Moreover, it underscores the material embodied nature of number sense, and compromises claims that number sense is innate.

Despite the findings of Lyons and Beilock (2011, 2013) and other similar research (Franklin, Jonides, & Smith, 2009; Turconi, Campbell, & Seron, 2006), the word “ordinal” features in the recently published 460-page *International handbook of dyscalculia and mathematical learning difficulties* (Chinn, 2015) exactly seven times (once in the references). This provides evidence of the prevailing focus on cardinality in the research literature, despite the findings of researchers such as Rubinsten and Sury (2011), who argue that DD may involve a deficit in non-symbolic ordinality, and not quantity processing. They suggest that linguistic knowledge may facilitate ordinal number processing, which is consistent with Seidenberg’s hypothesis and also revelatory of the difficulty of isolating any component of number sense, be it ordinal or cardinal.

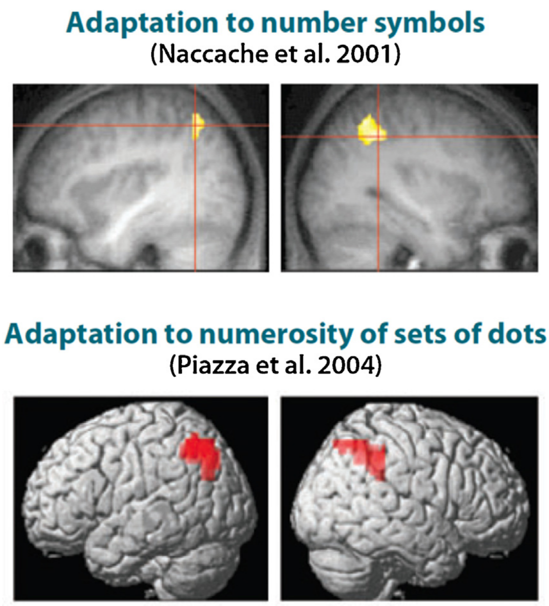

Fig. 3. Brain images adapted from Bugden & Ansari (2015).

While new tasks may be developed that can more fully address ordinal components of number sense, we are not arguing that such refinements will identify the true deficit of DD. Rather, we argue that the fundamentally temporal nature of ordinality demands an ontological shift in the way we think of number. We need to recognize number as an event, as an interval of time, rather than an object. By reducing ordinality to the set theoretic notion of an ordered set, we produce an image of number that is static rather than dynamic. The temporal dimension of ordinality is essential for reclaiming the time-value of computation, which is in turn essential for reclaiming the value of cognitive labour. In the next section, we show how this issue plays out in neurocognitive brain imaging of dyscalculics, where biomarkers of dis/ability are encoded into particular neuronal populations in which different groups of neurons perform different tasks.

5. Recruiting neuronal labour: the IPS

Whether focused on ordinal or cardinal aspects of number, several studies have shown that the intraparietal sulcus (IPS) is a hot seat of brain activity correlating to numerical tasks. The IPS has been referred to as "the region that houses the representational system of quantity regardless of notation" (Bugden & Ansari, 2015, p. 23). It is here that these researchers see the neuronal correlates of "numerical magnitude processing". Perhaps this region is the "ontogenetic neuronal origin" for processing numerosity, although there is evidence that children "recruit" other areas, such as the prefontal neural regions, and that the brain overall develops in such a way that the IPS becomes more functionally specialized. Fig. 3 shows the brain image of IPS activation when a participant performs the task of comparing numerals (above) and the task of comparing sets of dots (below).

Studies have shown that children with DD recruited the IPS less than children without (Bugden & Ansari, 2015, p. 26). Thus the IPS becomes a biomarker of ability in mathematics. Kaufmann, Vogel, Starke, & Schocke (2009) found that the activation of the right inferior parietal regions (including the IPS) differed significantly between children with and without dyscalculia in response to symbolic numerical processing. Rubinstein and Sury (2011) assert that, "intact development of the IPS is important for the development of ordinal skills" (p. 3). Further, Kucian et al. (2011) argued that children diagnosed with DD showed less "automated access to a spatial representation of numbers" (p. 782), by which they mean IPS neuronal correlates for a number line. The authors were testing a computer-based remediation programme in which students practised placing numbers along a number line.

The search for *number neurons* is thwarted, however, by the fact that the IPS and other brain regions intermingle: "there does not seem to be a single, isolated piece of cortex that responds solely to number; parameters of object size and location also seem to be coded by intermingled neuronal circuits distributed within the same general area of IPS" (Nieder & Dehaene, 2009, p. 196). Indeed, some research seems to suggest that finger pointing, grasping, eye movement, and attention are strongly linked to the IPS number neuronal activity (Culham et al., 2006). IPS activations do not cluster neatly for particular quantitative parameters, and brain imaging shows that number mingles with both size parameter and location parameter (Pinel, Piazza, Le Bihan, & Dehaene, 2004; Zago et al., 2008).

Despite this mingling, the IPS remains the focus of neurocognitive brain imaging research. One of the issues, however, is that the experimental equipment, which in this case is the fMRI, measures correlate activity with delay, and thus researchers are now turning to EEG and ERP and other techniques to get more immediate correlates.[5] This desire to find the neural correlate of arithmetic is problematized by the fact that verbal retrieval or manual actions are temporal and remain the visible lived experience that educators are interested in. Moreover, data indicating correlation between children's performance on symbolic magnitude comparison tasks and mathematical achievement do not yet substantiate the existence of any innate number system, since symbolic fluency is a highly regulated cultural practice. Additionally, there is a worrisome circularity involved in trying to distinguish the skills or behaviours of DD and non-DD participants when one is not sure how to define or identify the presumed disorder.

The issue in our estimation is that the research on DD would like to identify a core source for number sense that is atemporal and unrelated to memory and other material dimensions of lived experience. The role of working memory has been of particular interest, in part because researchers claim that children with mathematics learning disabilities do not preform as well on working memory tasks as typically achieving children do (see Geary, Hoard, Byrd-Crazen, Nugent, & Numtee, 2007) and because it has proven to be very difficult to tease working memory and number cognition apart. Brain imaging does suggest that the IPS is associated with individual differences in working memory and that activation levels of children with DD in the IPS reflect impairment of the working memory. But our review of the literature on DD and working memory showed little consensus. The issue seems to be the inherently complex and perhaps unknowable nature of memory, and in particular, the fact that memory is intrinsically temporal and linked to place, context and event.

This brings us back to the issue of cognitive labour. Labour happens in time; it takes time to make something, time to think and time to count, time to remember. If number sense is nothing more than an apparently instant activation of a neuron then there is no labour involved. This corresponds exactly to one of Marx's original notions of alienation, which involves the alienation from the time dimension of labour. Tacit assumptions about labour creep into the research findings in this field, as in Crespo and Castro (2015) who interpret brain images of DD who recruit more distributed brain regions as "effortful number processing", implying that only in the case of DD is cognitive labour "effortful", while neurotypicals labour without effort.

[5] fMRI: Functional magnetic resonance imaging; EEG: electroencephalography; ERP: event-related potentials.

Cognitive labour at this neurological scale is denied temporality and split between different neuronal populations. One of the most prominent models in explaining the neuronal correlates of number sense identifies different neurons that "encode" different aspects of number. The "Triple Code Model" describes how different neurons perform different tasks (Bugden & Ansari, 2015). But to our point, this model also maps the computational brain, territorializing and segmenting the brain, to show how different populations of neurons produce different kinds of value. The Triple Code Model describes the encoding activity of neurons and not brains. The *neurons* are performing the numerical judgements and calculations in response to electrical stimuli, and thus the entire notion of human agency is shifted to the neuron. In the next section we discuss how this shift in assigning agency to the neuron is part of a wider shift in computational approaches to cognition.

6. Rethinking the biopolitics of the body

Neurocognitive research on mathematics dis/ability is redefining how mathematical competencies are performed and observed. Through this research, and related policy, the student's body is being reconfigured and reassembled. The conventional understanding of how a learner "knows" mathematics is changing, and this change entails a simultaneous change in what constitutes number. As number neurons take on a more significant role in student achievement, the question as to what or who is doing mathematics is raised. Dystopic images of brains in vats come to mind, as they should, but this is not the time to retreat to a social model of dis/ability that denies the material force of neurons. Such an approach fails to track the labour that neurons *actually do*, the value they create, and the way that value may or may *not* be recuperated by the human body. In other words, the neuron is currently being isolated as a worker 'whose' labour can be tapped and managed. This decidedly nightmarish situation is also where we must turn, however, if we hope to generate an approach to dis/ability that is adequate to the accelerated flows of advanced capitalism. We need to find new ways of studying how the neuron participates in learning events, not simply as a biomarker of dis/ability. We would like to see new kinds of questions posed by researchers, questions that can help us build more complex models of bodily activity, so that we do not become trapped in overly simplistic models of stimulus-response. For instance, how might we study neuronal patterns of activation as emergent rather than simply reactive? In related efforts, recent work in anthropology has turned to the study of "biosocial becomings" and "bio-semiotics" in order to better understand how the social and the biological operate at all scales, beneath and beyond the human (Ingold & Pallsan, 2011).

In this we follow Deleuze and Guattari (1987) who offer a way of thinking the political at diverse scales, tracking traits and flows of capital across the molecular and the molar. In their claim that "every politics is simultaneously a *macropolitics* and a *micropolitics*" they shift focus to the molecular and imperceptible level and to what they call "the micro-fascisms" that operate beneath and beside the human subject (*italics in original*, p. 213). This molecularization of politics has the potential to radically open up our research to new ways of attending to the biopolitics of life and to track alienation in new ways. Deleuze and Guattari (1987) will argue that macro-politics are plugged-into micro-politics, through a molecularization of agency:

> Politics on the grand scale can never administer its molar segments without also dealing with the micro injections or infiltrations that work in its favor or present an obstacle to it; indeed, the larger the molar aggregates, the greater the molecularization of the agencies they put into play. (p. 204)

These micro-injections and infiltrations break through the skin and reorganize the bounded body according to new forces and new desires. The human body becomes a recombinant subject, engaged in distributed decision-making and network forms of becoming. The individual is divided, repeatedly, replaced by disparate trajectories of "dividuals"—a term that Deleuze and Guattari introduce to describe the traits that break free from the bounded human body, circulating as part of the cognitive economy. Global capital links the mobile dividuals in a vast network that is highly flexible and transindividual. Thus the individuated human body, upon which theories of labour and capital were built, is disassembled through Deleuze and Guattari's concept of dividuation and *becoming molecular*. This approach underscores the way in which capitalism extracts value at all scales and speeds, whether it be from the human qualities (race, gender, sexual orientation, etc.) or from the labour of non-human molecular interaction like neurocognitive labour. We currently live in a world in which the 'fast' number neuron has broken free of the conventional body, circulating as part of the cognitive economy, in which quick judgements of cardinality define school mathematics. But there is an opening up to the potentiality of the body.

This approach has been taken up in the critical dis/ability literature. Shakespeare and Watson (2001) argue for an affirmative movement, where dis/ability is redefined as "[t]hat in the body which exceeds deterministic efforts to predict a life trajectory" (Snyder & Mitchell, 2001, p. 377). The disability theorist James Overboe takes on this task by arguing for an "impersonal life". Overboe (2009) borrows the term impersonal life from Deleuze so as to study 'a' body that does not belong to us in any definitive way—it is *not* personal. An impersonal life is a life that is networked and entangled in ways that trouble the conventional conception of person, and that allow for a radical potentiality. This impersonal life is a "pre-reflexive and impersonal consciousness, a qualitative duration of consciousness without a self . . . " (Deleuze, 2001, p. 25). The disability theorist Goodley (2009) suggests that "the metaphor of the body as organism refers to an endemic societal view of the body as sovereign self: contained, knowable, measurable, and dis/abled" (p. 264). These developments in dis/ability theory are now studying sensation as that which is dispersed across an event, where a body is always becoming individuated with a provisional set of organs open to constant reorganisation.

Clearly, the human body must be considered an organism at crucial moments, often at times of physical crisis; and bodies are regularly sustained as such through medical treatment. This we are not denying. But we are provoking the reader to consider how the question of *time*, and its role in the way we think about and with bodies, can shed new light on dis/ability and the slow-firing neurons (or the longer circuitous synaptic connections) of a dyscalculic IPS. We tend to think of human bodies as physical objects, some more animate than others, which typically directs our attention to how bodies are individuated and *possess* particular abilities and disabilities. Instead, we suggest that bodies are temporal *through and through*, and *that there is no body that is not ultimately an event or interval of time*. Deleuze will focus on the *differential quantities* that sustain or individualize a body, rather than validate the organic image of the body as organism. If bodies are relations of speed and rest, then they are in continuous process, and open to radical reconfiguration. Organs are contracted and sustained *over time*, and are de-essentialized. It is not that the organs themselves are unimportant, but that we need to look past the particular arrangement of the organs known as the organism in order to study new forms of labour. If one succeeds at inverting this tendency, and pursuing this inversion in a methodical manner, then organs are no longer sensory, but simply speeds or quanta of differentiation (rates of change). Such an approach allows us to study how flows of capital reconfigure the borders around bodies, and produce new kinds of labouring bodies. It also allows us to study the way that bodies are provisionally and temporarily enabled, directing our attention to the temporal contingency of dis/ability.

7. Conclusion

The increasing importance of brain research in education and social policy demands a new way of thinking about alienation. In this paper, we have focused on how this research is reconfiguring the human body, and altering the way we recruit value from its labour. What we see in the neurological work on dyscalculia and number sense is a turn to discussions of “neuronal populations” and regions where such populations operate according to built-in competencies. The working assumption, inherited from early cybernetics, although modulated to address new evidence, is that each neuron is a kind of “logic gate” that assigns true/false each time it is activated by an impulse. When Pitts and McCulloch proposed the “neural net” in the 1940s as a way of thinking about computation and communication, they created an equivalence between brain activity and yes/no adjudication. *Thus the decision capacity of the human is transposed to the neuron*. In other words, the “distributed cognition” that many learning theorists embrace today, is in this case distributed across populations of neurons as much as it is distributed across a set of human bodies in a sociotechnical network.

This move has radical implications for how we think about learning. It is a move from perception to cognition, from the perceiving body to the user, from the human body as organism to the human body as computation. Like previous territorializing of the human body by bio-politics, the move is always to track the limit of human perception and turn it into the source for technical innovation and the governance of new populations—this time populations of neurons. What current work on DD does is attenuate the nervous system, and stretch the network of distributed cognition deep into different territories of the brain. The dot test is a test for pattern recognition. If the brain is that which consumes information and finds patterns, the learner becomes a node in a network with particular channel capacities. This crucial shift in learning theory undermines the very notion of a learner as someone who identifies more or less with the norms of a human population. Previous notions of subjectivity that posit a stable norm against which one reacts or conforms (the good student or the white student) are displaced by new relations between populations of neurons and electrical impulses. This reflects an important paradigm shift in education research, demanding new biosocial theories that are adequate to the ethics of this situation. As researchers attend to the ‘more than human’, linking neurons directly to automated sources for modulating stimulus, previous conceptions of alienation seem insufficient to address our concerns.

In this paper, we have emphasized the temporal dimension of cognitive labour as the issue that seems at stake in the research on number sense, stressing that experimental emphasis on cardinality forecloses on the temporality and potentiality of human bodies. Although this paper has been critical of certain biases in neurocognitive research, our objective has been to provoke researchers to take up the neuron in new ways. Neurons are bodies, as well as being parts of human bodies, and we need to find inclusive ways of studying how they participate in learning events. Rather than abandon the neuron and dismiss all neurocognitive research, we want to invest in the possibility of neurocognitive research that does not serve the computational dream of a control society. Others in the social sciences are pursuing related agendas, looking for the “potential in the neurosciences for reinvention and transformation” (Wilson, 2004, p.13). Rose (2013), for instance, pursues “an affirmative relationship” with an emerging “new and non-reductive biology of human beings and other organisms in their milieu,. .. which can thus be brought into conversation with. .. the social and human sciences” (p. 24). On the other hand, ebullient affirmations of brain research without adequate critique, as sometimes found in current work on affect, need to be interrogated (Papoulias & Callard, 2010). And interdisciplinary projects across the social and biological sciences are often sites where “the biosocial nexus starts to look distinctly bio-centric” (Fitzgerald & Callard, 2015, p. 14). In light of these various concerns, we hope to see more research into the complex lived experience of time, memory and number in critical conversation with neurocognitive research.

References

American Psychological Association (2013). *Diagnostic and statistical manual of mental disorders*, 5th ed. Washington, D.C: Author.
Berardi, F. (2009). *The soul at work: from alienation to autonomy (F. Cadel., & G. Mecchia, Trans.)*. Los Angeles, CA: Semiotext(e).

Borgioli, G. M. (2008). A critical examination of learning disabilities in mathematics: applying the lens of ableism. *Journal of Thought*, *43*, 131–147.
Bugden, S., & Ansari, D. (2015). How can cognitive developmental neuroscience constrain our understanding of developmental dyscalculia? In S. Chinn (Ed.), *International handbook of dyscalculia and mathematical learning difficulties* (pp. 18–43). London: Routledge.
Butterworth, B. (2005). Developmental dyscalculia. In J. Campbell (Ed.), *The handbook of mathematical cognition* (pp. 455–467).Psychology Press.
Chinn, S. (2015). *The Routledge International handbook of dyscalculia and mathematical learning disabilities*. London: Routledge.
Coles, A. (2014). Ordinality, neuro-science and the early learning of number. In C. Nichol, S. Oesterle, P. Liljedahl, & D. Allen (Eds.), *Proceedings of the joint PME 38 and PME-NA 36 conference:* (2. pp. 329–336).Vancouver, BC: PME.
Culham, J. C., Cavina-Pratesi, C., & Singhal, A. (2006). The role of parietal cortex in visuomotor control: what have we learned from neuroimaging? *Neuropsychologia*, *44*, 2668–2684.
Dehaene, S. (1997). *The number sense*. New York: Basic Books.
Dehaene, S. (2011). *The number sense: how the mind creates mathematics*. New York, NY: Oxford University Press.
de Freitas, E. (2014). How theories of perception deploy the line: reconfiguring students' bodies through topo-philosophy. *Educational Theory*, *64*(3), 285–301.
de Freitas, E., & Sinclair, N. (2014a). *Mathematics and the body: material entanglements in the mathematics classroom*. New York: Cambridge University Press.
de Freitas, E., & Sinclair, N. (2014b). The politics of the mathematic aesthetic: curricular con(sens) us and acts of dissensus. *Philosophy of Mathematics Education*, *28*(October) http://people.exeter.ac.uk/PErnest/pome28/index.html Accessed 11.10.15..
Deleuze, G. (2001). *Pure immanence: essays on a life*. New York: Zone Books.
Deleuze, G., & Guattari, F. (1987). *A thousand plateaus: capitalism and schizophrenia*. Minneapolis: University of Minnesota Press.
Eide, B. L., & Eide, F. F. (2011). *The dyslexic advantage: unlocking the hidden potential of the dyslexic brain*. New York: Penguin.
Emerson, J., & Babtie, P. (2015). *The dyscalculia solution*. London: Bloomsbury.
Fitzgerald, D., & Callard, F. (2015). Social science and neuroscience: beyond interdisciplinarity. Theory. *Culture and Society*, *32*(1), 3–32.
Franklin, M. S., Jonides, J., & Smith, E. E. (2009). Processing of order information for numbers and months. *Memory & Cognition*, *37*, 644–654.
Geary, D., Hoard, M., Byrd-Crazen, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development*, *78*(4), 1343–1359.
Geyer, R. F., & Schweitzer, D. R. (Eds.). (1976). *Theories of alienation*. Leiden: Martinus Nijhoff.
Gifford, S. (2006). Dyscalculia: myths and models. *Research in Mathematics Education*, *8*, 35–51.
Gifford, S., & Rockliffe, F. (2008). In search of dyscalculia. *Proceedings of the British Society for Research into Learning Mathematics*, *28*(1), 21–27.
Goodley, D. (2009). Bringing the psyche back into disability studies: the case of the body with/out organs. *Journal of Literary & Cultural Disability Studies*, *3*(3), 257–272.
Hallahan, D. P., & Mock, D. R. (2006). A brief history of the field of learning disabilities. In H. L. Swanson, K. R. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 16–29).New York: The Guilford Press.
Kaufmann, L., Mazzocco, M. M., Dowker, A., von Aster, M., Göbel, S. M., Grabner, R. H., et al. (2013). Dyscalculia from a developmental and differential perspective. *Frontiers in Psychology*, *4*, 516.
Kaufmann, L., Vogel, S., Starke, M., & Schocke, M. (2009). Numerical and non-numerical ordinality processing in children with and without developmental dyscalculia: evidence from fMRI. *Cognitive Development*, *24*, 486–494.
Kucian, K., Grond, U., Rotzer, S., Henzi, B., Schönmann, C., Plangger, F., et al. (2011). Mental number line training in children with developmental dyscalculia. *Neuroimage*, *57*(3), 782–795.
Linton, S. (1998). *Claiming disability: knowledge and Identity*. New York: New York University Press.
Lyons, I., & Beilock, S. (2011). Numerical ordering ability mediates the relation between number-sense and arithmetic competence. *Cognition*, *121*, 256–261.
Lyons, I., & Beilock, S. (2013). Ordinality and the nature of symbolic numbers. *The Journal of Neuroscience*, *33*, 17052–17061.
Mechner, F. (1958). Probability relations within response sequences under ratio reinforcement. *Journal of the Experimental Analysis of Behavior*, *1*, 109–121.
National Council of Teachers of Mathematics (2014). *Principles to actions: ensuring mathematical success for all*. Reston, VA: NCTM.
Nieder, A., & Miller, E. K. (2003). Coding of cognitive magnitude: compressed scaling of numerical information in the primate prefrontal cortex. *Neuron*, *37*, 149–157.
Nieder, A., & Dehaene, S. (2009). Representation of number in the brain. *Annual Review in Neuroscience*, *32*, 185–208.
Overboe, J. (2009). Affirming the impersonal life: a different register for disability studies. *Journal of Literary & Cultural Disability Studies*, *3*(3), 241–256.
Papoulias, C., & Callard, F. (2010). Biology's gift: interrogating the turn to affect. *Body & Society*, *16*(1), 29–56.
Peters, M., & Bulut, E. (Eds.). (2011). *Cognitive capitalism, education and digital labor*. New York: Peter Lang.
Pinel, P., Piazza, M., Le Bihan, D., & Dehaene, S. (2004). Distributed and overlapping cerebral representations of number, size, and luminance during comparative judgments. *Neuron*, *41*, 983–993.
Reigosa-Crespo, V., & Castro, D. (2015). Dots and digits: how do children process the numerical magnitude? Evidence from brain and behaviour. In S. Chinn (Ed.), *International handbook of dyscalculia and mathematical learning difficulties* (pp. 60–77).London: Routledge.
Rips, L. (2015). Beliefs about the nature of numbers. In E. Davis, & P. David (Eds.), *Mathematics, Substance and Surmise* (pp. 321–345).New York: Springer.
Rose, N. (2013). The human sciences in a biological age. *Theory, Culture & Society*, *30*(1), 3–34.
Rubinstein, O., & Sury, D. (2011). Processing ordinality and quantity: the case of developmental dyscalculia. *PLoS One*, *6*(9) Epub.
Seidenberg, A. (1962). The ritual origin of counting. *Archive for History of Exact Sciences*, *2*(1), 1–40.
Shakespeare, T., & Watson, N. (2001). The social model of disability: an outdated ideology? In S. N. Barnartt, & B. M. Altman (Eds.), *Exploring theories and expanding methodologies: where we are and where we need to go. Series in social science and disability:* (Vol. 2. pp. 9–28).Amsterdam & New York: JAI.
Snyder, S. L., & Mitchell, D. T. (2001). Re-engaging the body: disability studies and the resistance to embodiment. *Public Culture*, *13*(3), 367–390.
Turconi, E., Campbell, J. I. D., & Seron, X. (2006). Numerical order and quantity processing in number comparison. *Cognition*, *98*, 273–285.
Williams, J. (in press). Alienation in mathematics education: critique and development of neo-Vygotskyan perspectives. *Educational Studies in Mathematics*.
Wilson, E. A. (2004). *Psychosomatic: feminism and the neurological body*. Durham, NC: Duke University Press.
Zago, L., Petit, L., Turbelin, M. R., Andersson, F., Vigneau, M., & Tzourio-Mazoyer, N. (2008). How verbal and spatial manipulation networks contribute to calculation: an fMRI study. *Neuropsychologia*, *46*, 2403–2414.