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From science wars to transdisciplinarity: the inescapability of the neuroscience, biology and sociology of learning

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ABSTRACT
In this paper we begin to explore how knowledges being generated in bioscience might be brought into productive articulation with the Sociology of Education, considering the potential for emerging transdisciplinary, 'biosocial' approaches to enable new ways of researching and understanding pressing educational issues. In this paper, as in our current research, we take learning as our focus. Our work brings together collaborators from across fields: sociology of education; molecular biology and biochemistry; cognitive neuroscience; fMRI imaging; and EEG. Through the paper we explore the generative potential of an encounter between life sciences and sociology of education. Through consideration of the conceptual and methodological elements of our 'Synchrony in Learning' research and engagement with our pilot experimental approach, our research is suggesting that our central concept, learning, is undergoing metamorphosis, challenging us to understand learning as a phenomenon produced through the intra-action of a multiplicity of forces and processes.

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Introduction

In this paper we begin to explore how knowledges being generated in bioscience might be brought into productive articulation with the Sociology of Education, considering the potential for emerging transdisciplinary, 'biosocial' approaches to enable new ways of researching and understanding pressing educational issues. In this paper, as in our current research, we take learning as our focus. We situate our work by exploring sociological critique of science and concerns over the dangers of biological knowledges, including in education, and locate both recent flashpoints and mediations that at once suggest caution and possibility. Drawing on the Baradian (2007) notions of entanglements and intra-action, we argue that the social cannot be extracted from the biological. Through the paper we explore the generative potential of an encounter between life sciences and sociology of education for understanding learning, and conclude that attending to social and biological entanglements has conceptual and practical potential. A key purpose of the paper is to present a way of moving beyond

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the longstanding tendency for Sociology of Education to be orientated critically towards biosciences. (Youdell 2017; Youdell, Harwood, and Lindley 2018; Youdell and Lindley 2018).

The paper brings together the work of collaborators from across fields: Youdell, a sociologist of education; Lindley, working across molecular biology and biochemistry; Shapiro, a cognitive neuroscientist in the field of working memory; Sun, a specialist in fMRI imaging; and Leng, a specialist in EEG (electroencephalography). This research collaboration and co-authorship across disciplines offers one example, after Malabou (2009), of the 'metamorphoses' that transdisciplinary working can provoke. Through the paper we hope to identify the generative potential of an encounter between life sciences and sociology of education for understanding learning.

To do this we begin by setting out a conceptual framework for understanding entanglement and transformation. We consider how the Science Wars have given way to new allegiances and transdisciplinary work, even as powerful tensions remain. Moving on to our key focus—learning—we explore the fragmented nature of knowledge and theories of learning across and within disciplines, and the limits to understanding learning's blockages and vectors that this fragmentation brings. We highlight state of the art insights into learning from across disciplines and advocate a critical biosocial approach to research on learning. Drawing on our collaborative research across the UK and Nanjing, China, we detail how we are proceeding to undertake transdisciplinary research into the social, relational, pedagogic, neural and biochemical features of learning, foregrounding the significance of synchrony. Ultimately, we advocate an open orientation to transdisciplinary working in sociology of education and a metamorphosis of the concept of learning.

Conceptual framework: entanglements and transformations

Entanglement

This paper and the research into learning that it reports, is underpinned, at least for the sociologist of education amongst us (Youdell), by a Baradian understanding of intra-action (Barad 2007) coupled with the Deleuzian understanding of assemblage (Deleuze and Guattari 2008). In *Meeting the Universe Halfway* (2007) Barad sets out a careful account of the entanglement of phenomena that are frequently treated, in science and sociology alike, as discreet and potentially of different orders. The persistent, and at times unexpected, entanglement that Barad identifies leads to her argument for an understanding of and methodological orientation towards intra-action; apparently discreet phenomenon are fundamentally enfolded such that they are understood to *intra*-act, not inter-act. This orientation suggests that the e.g. social, cultural, neural and biochemical are fundamentally enfolded and implicated in each other; they are in intra-action. Likewise the Deleuzian (Deleuze and Guattari 2008) notion of assemblage alerts us to the mobility and multiplicity of forces as these move into complex productive relationships with each other, generating complex social formations, and there is a growing body of work utilising the Deleuzian notion of assemblage to examine the entanglement of the social and the biological (cf Tessier 2019; Abrams et al. 2019). For the natural scientists in our group these Baradian and Deleuzian foundations are less significant, but the recognition of complexity and the multiplicity of influences remains (alongside the desire to isolate influences for precise investigation). As we pursue our research into learning, then, we posit that learning itself should be understood as a complex social formation, as produced through the flows of multiple forces in assemblage, and that understanding these forces and their intra-action has the potential to teach us something new about learning.

From science wars to transdisciplinarity

This orientation to intra-action, including the intra-action of forces or factors which might ordinarily be seen as belonging to discreet domains of knowledge and disciplines—such as e.g. relationships between teachers and students and neural activity—is some way from the 'Science Wars' that dominated the exchange between social science and natural sciences in 1990s. The long running and at times heated debate between social and natural scientists over the nature of social and scientific knowledge, the recognition of the complexities that constructivist accounts provide, and their rebuttal as naive and relativist has shaped (or limited) the potential terrain for transdisciplinary encounters. (See e.g. Barringer 2001; Collins and Pinch 1993; Gross and Levitt 1994; Latour and Woolgar 1979; Nelkin 1996; Parsons 2003).

A version of these debates can also be seen in education in what we might call the 'IQ Wars'; an at times heated contest over the nature of 'intelligence' and the role of institutions in shaping and foreclosing the opportunities available to minoritised students. In the 1990s in the UK this debate hinged around competing approaches to measuring school performance and race and ethnic 'gaps' in these, contest over the veracity of twin studies of variance, as well as competing underpinning epistemological orientations (Foster, Gomm, and Hammersley 1996; Gillborn and Gipps 1998, Foster and Hammersley 1998). More recently this debate has taken new shape as developments in genetics, and in particular the methods, data banks and computing power to drive large scale genome wide association studies (GWAS) have sought new forms of measurement and evidence of 'intelligence' and its variability (Ashbury and Plomin 2014; Gillborn 2016; Plomin 2018), and critical research has responded through the deployment of QuantCrit—quantitative methods and analyses interrogated and deployed within a Critical Race Theory framing (Crawford 2018; Gillborn et al. 2018).

The Science Wars cooled in the 2000s and in the last decade or so a shift in orientation has taken place which has seen a number of critical social theorists developing new modes of engagement with natural sciences, and natural scientists engaging in new ways with social theory and social science, not least Karen Barad's move from physics into social theory (Barad 2007). Particularly notable are the new allegiances across social and science disciplines forged in relation to the climate crisis. Emerging work in social science and social theory on climate crisis and activism is underscoring the limits of politics and activism as it is usually configured (Piotrowski 2017, 2018). Bruno Latour, whose *Laboratory Life* (Latour and Woolgar 1979) was a key target of the Science Wars, is newly engaged in transdisciplinary collaborative work with climate scientists (de Vrieze 2017). And Donna Haraway, whose *Cyborg Manifesto* (Haraway 1985) observed and advocated the porosity of boundaries between human, animal and machine, is now engaged in climate activism and scholarship through her work on the 'Chthulucene' which highlights the perilous state of the earth and the inter-species 'making-with' and 'reworlding' that is urgently needed (Haraway 2015).

Education's encounter with neuroscience

Social scientists writing about the engagement with neuroscience in education have expressed concerns that when education is coupled with neuroscience or prefixed with 'neuro' this is done with the assumption that neuroscience brings a 'novel explanatory framework' (Rose and Abi-Rached 2013, 6 cited by Aronsson and Lenz Taguchi 2018, 242) that will 'solve' problems or 'fill' knowledge gaps that the field of education is constituted as carrying. When such a 'transdiscipline' as 'education neuroscience' is pursued, it is argued, neuroscience is transposed into education and situated as education's saviour or corrective, and, therefore, as the dominant or lead discipline (Baker and Saari 2018; Lenz Taguchi 2016; Aronsson and Lenz Taguchi 2018). Hillevi Lenz Taguchi and colleagues argue that education and neuroscience collaborations are regularly framed in terms of reciprocity which posits mutual benefit and integration as a 'goal in itself' (Lenz Taguchi in review). Citing Bruer's (1997) early advocacy of such reciprocity, Lenz Taguchi (in review) highlights its orientation towards 'bridging' between science, cognitive psychology, education. She notes, however, that rather than being an open-ended exchange, this bridging embeds an assumed and enduring hierarchy across these disciplines that values science most highly and positions cognitive psychology as the most privileged bridge that connects the other two. Lenz Taguchi also notes the regular absence of education researchers in the apparently transdisciplinary endeavor of education neuroscience. At the same time, she notes the persistence of concerns about education neuroscience voiced by education researchers, suggesting some concerns reflect these embedded hierarchies and some reflect an excessive aversion that acts to block possible encounters. These relations and limits are understood as epistemological and methodological:

> [W]e understand these differences in terms of how and why knowledge is produced in a certain way, and what kinds of knowledge such productions enable: i.e. epistemological and methodological differences that are not [intrinsically] hierarchically ordered and valued. (Lenz Taguchi in review, 4–5).

This resonates with our own concerns over the way that engagements between critical education research and natural sciences are governed by the 'speakablity' of such encounters. We have suggested that insights from the sociology of knowledge in education allied with the Bultlerian notion of speakability (Butler 1997)—what can be said and makes sense within a particular discursive framing—help us to understand what can and cannot be asked in sociology of education and in more general education research (Youdell and Lindley 2020).

Transformation: how to work 'transdisciplinarily'

Lenz Taguchi offers a way through these epistemic and methodological limits by suggesting that we proceed by asking: '*why* and in *what ways* education—educational instruction *and* research—needs the neurosciences?' and 'do the neurosciences need *education*?' (Lenz Taguchi in review, 9). Aronsson and Lenz Taguchi (2018) look to 'creatively reconfiguring [education and neuroscience] in the encounter' (242). These questions and reconfigurations are also pertinent in relation to the range of biological sciences that we and others have engaged: why and what ways might sociology of education, molecular biology, analytical chemistry or epigenetics need each other? (cf Youdell and Lindley 2018).

What is suggested, then, is collaborative research that avoids discipline hierarchies, identifies shared underpinning values, works to develop shared research questions which then lead to shared methodological decisions (Lenz Taguchi in review, Youdell and Lindley 2018). This entails a movement away from thinking in terms of the 'application' of neuroscience or biological science in education to an approach to transdisciplinary research that is based in education and educators values (Callard and Fitzgerald, 2015). Likewise, Liz de Freitas at the MMU Biosocial Research Lab emphasises the need to 'move beyond the agonistics of critique and towards creative experimentation and the development of new theory' (de Freitas 2018, 293) in the encounter between the social and the biological.

Furthermore, the recognition of the multi-directionality of influences across these domains requires us to:

> [D] evelop concepts and methods for understanding and describing biological forms of human life that emerge within, and are reproduced by, specific kinds of social, political and economic relations (Fitzgerald, Rose, and Singh 2016, 16 cited by Williamson, Pykett, and Nemorin 2018, 260).

Williamson, Pykett, and Nemorin 2018 argue that education environments are now mediated by new biological and neuro- knowledges and technologies themselves driven by global technology and publishing companies such as Pearson and IBM. Given this, they argue, we need new ways of thinking about education, learning and learners. They suggest the concept of 'brain/code/space' to capture the transformations to education environments rendered at once brain-based and brain-targeted, and the 'new forms of neurocomputational governance' that these knowledges and technologies allow; changes 'which have the potential to reshape education and learner identities' (Williamson, Pykett, and Nemorin 2018, 259).

Kalervo Gulson and Taylor Webb (2016; 2018) have been key analysts of the social and political implications for education of popular interest in and education policy mobilisation of emerging molecular knowledge of the body and techniques for understanding life 'computationally'. They identify how, grounded in data science, a 'molecular biopolitics' is now embedded in education. Gulson and Webb point out that traditional disciplines—humanities, social science as well as life and computing sciences—are unable individually to understand current transformations of life that are being inaugurated by new technologies and new biosciences. They say:

> We suggest these advancements in life and computing sciences will not only demand the critical rethinking of the residual historical images of biology and education, but these may further demand new concepts and thinking through ideas of life for understanding and doing educational policy and practice. (Gulson and Webb 2018, 277).

Again, the problematics as well as the necessity of generating new ways of thinking about and doing research in education is emphasised.

A critical biosocial turn?

As this discussion demonstrates, we have seen the emergence of a body of 'biosocial' scholarship across the social sciences, including in education, which acknowledges the infolding of the social and biological in the making of humans and which has sought to surface potential new insights through engagement of and collaboration with natural sciences (Frost 2016; Roberts 2015; Wilson 2015; Youdell & Lindley 2018). Celia Roberts has extended the 'biosocial' and tethered together the 'bio-psycho-social' in her analysis (Roberts 2015) and Samantha Frost has eschewed the biosocial and moved to thinking in terms of the 'biocultural' (Frost 2016).

Echoing the concern with the ways that schools are implicated in social reproduction within the 'new sociology of education' of the 1970s, and sharing its central concern with the constitutive and constraining role of knowledges, we provisionally identify these movements in scholarship as something like a 'new critical biosocial turn' in education (although we are uncertain that there is sufficient momentum to really claim this as a 'turn'). This orientation as part of a new and critical biosocial turn situates current sociological concerns with phenomena such as feeling, embodiment, the cultural coding of the body, and the productive relationships between bodies, feelings and social milieu in the convergences of a broad, transdisciplinary field.

The problem of learning

As we have explored across our disciplines our shared values and questions, a concern to better understand learning and how it is both blocked and facilitated has emerged.

Some of us have argued previously that a partial and fragmented understanding of what constitutes learning, what it is influenced by, and what its mechanisms might be is a key, persistent problem for education (Youdell 2017; Youdell & Lindley 2018). We note that across sub-fields of education what learning 'is' is understood differently: in curriculum, pedagogy and assessment research the focus is on what is learnt, through what processes, and with what outcomes (James et al. 2012; Pollard et al. 2005); in educational psychology research the focus is on developing cognition (Cohen Kadosh & Dowker 2015); and in education sociology and policy sociology the focus is on the structures, systems and practices that shape and constrain the possibilities for learning and what learning is taken to be (Youdell 2011; Ball 2013). Research in education has developed understandings of the significance of a variety of factors that appear to influence learning. Key among these are different pedagogic approaches and materials (Gore et al. 2004; James & Pollard 2012); pedagogic relations and the way that these shape students' engagement and experience in the classroom (Bibby 2017; Lingard et al. 2003); students' sense of themselves as learners and whether they are recognised as 'good' learners by peers and teachers (Youdell 2006, 2011); and the associated feelings that circulate in classrooms (Hickey-Moody 2014; Kenway and Youdell 2011; Youdell and Armstrong 2011). Synthesis of these discreet bodies of education research demonstrates the centrality of relationships for learning (Youdell & Lindley 2018)

These sub-fields within education have generated rich insight into the ways in which learning is situated and constituted, and have been mobilised to understand better how learning might be facilitated. Nevertheless, so far the integration of thinking across these sub-fields is not extensive. Furthermore, sociological engagements with the fundamentally embodied nature of learning remain interpretive, and the biological processes of the body—from electrical activity in the brain and beating hearts to metabolic pathways within cells and movements across membranes—remain out of reach.

Work by Elizabeth de Freitas responds to this limit by engaging with new biotechnology e.g. electro-dermal activity sensors (EDAs), in the form of small wrist watch-like devices, which monitor heart rate, skin temperature, and perspiration. Such biosensors and the data they generate, she suggests, might be used to research a 'more-than-human worldly sensibility' and develop post-human theories of learning because of the way that biosensor data can be used to illuminate the 'profoundly relational and materially distributed nature of learning' (de Freitas 2018, 292). Importantly, de Freitas argues that the bio-data generated from biosensor devices worn by individual learners should be understood as *belonging to the learning environment* rather than just the individual body on which the biosensor is worn. This is because that biodata is manifest as a result of the body's entanglement in the environment and its practices as 'part of the radical exteriority of experience' (294). For de Freitas this means that biosocial research should be recast as 'the ecological study of complex dynamic systems' (ibid). This move has the potential to liberate biosensors and their data, as well as other bio- and neuro- technologies and the data these are able to generate, from the charge that they are inextricably implicated in the molecular-bio-politics of governance. She says:

> Rather than demonize the technology as an extraction device that fails to capture lived experience, we need to find better ways to think about these new kinds of digital plug-ins, different ways of understanding the significance of the EDA data. This involves theorizing the wristbands as a means of plugging into an environmental sensibility, a way of connecting with the machinic dimension of generative activity. (de Freitas 2018, 299).

The neuroscience, biology and sociology of learning

Understandings of learning from neuroscience are markedly different to educational understandings of learning. For example, neuroscientist Koizumi defines learning as 'the biological process to form neural circuits, [that] consists of morphological and functional connectivities of the synapses' (Koizumi's 2012, 320 cited by Lenz Taguchi in review, 10). While neuroscientists are actively engaged in the study of learning, there is both enthusiasm and caution in the claim to a 'science of learning' and 'education neuroscience' (Arwood and Meridith 2017; Fischer et al. 2010; Goswami 2006; Howard-Jones 2014), as well as concerns about a rush to commercialisation of technology such as transcranial stimulation devices for the classroom (Williamson 2019). Key advocates of the relevance of neuroscience for education point to the need for more basic research (Fischer et al. 2010) and critical scholars point to the dependency of fields on their objects of study: '[t]he concept of learning affords the existence of cognitive neurosciences, just as it affords the existence of education.' (Lenz Taguchi in review, 10).

Neuroscience research has done much to show the interplay of daily life experience and brain development, structures, functions, and connectivity, and demonstrated the brain's plasticity. Cognitive neuroscience that is concerned with attention (Shapiro and Hanslmayr 2014) and working memory (Jackson et al. 2011) has particular potential for helping us understand learning in education context. Current research in education neuroscience explores a range of neuroscience-informed pedagogic approaches that might enhance learning, for instance in relation to improvements in language and reading for children facing difficulty in these areas (Goswami 2014; Kyle et al. 2013; Plak et al. 2016) and the manipulation of reward in the classroom (Mason et al. 2017). In the UK cognitive load theory (CLT) (CESE 2017; Sweller 1994) has been mobilised by Ofsted, the school inspection agency for England, and embedded in the school inspection framework as an official school inspection criteria, demanding that school practices be informed by cognitive load theory, and making recommendations for how this might be achieved in practice. Research by Len Taguchi and colleagues (Frankenburg et al. 2018) is augmenting a broader study of different pedagogic approaches in Swedish Kindergarten classrooms by using EEG measurement of changes in brain activity, using the Event Related Potential (ERP) paradigm.

Brain synchrony

In this wider context, research in neuroscience has recently explored synchrony of brain oscillations and memory formation. Research by Clouter et al. (2017) (of which one of us (Shapiro) is an author) explores synchrony and memory formation, underpinned by the understanding that episodic memories are often multisensory and demand the binding different elements that are processed in specialized but distinct brain modules and rely on the precise timing of neural activity. The research involved a memory task experiment which required participants to remember associations between pairs of short movies and sound clips (3-s duration each). Remembering image-sound pairs of this sort demands 'cross-domain' (auditory/visual) associative binding and so depends on hippocampal function.

The research demonstrates that the degree of synchrony between visual and auditory stimuli during memory formation modulates recall, such that synchronized sensory stimuli increase human associative memory. Specifically, Clouter et al. show that memory formation depends on precision coordinated timing of audio-visual inputs in the theta frequency range (4 Hz) (this was not found in slower (1.7 Hz) or faster frequencies (10.5 Hz)). Their findings provide the first direct evidence that episodic memory formation in humans depends on phase synchrony between different sensory cortices at the theta frequency (see Figure 1).

Work in social neuroscience from the Suzanne Dikker lab explores social interaction in learning situations and the way that oscillations synchronise in the brain activity of students and teachers working in pairs and groups. Through this work brain-to-brain synchrony has been found in pair and group interactions, is shown to predict memory retention, and has been connected to forms of instruction, teacher-student relations and learning outcomes (Bevilacqua et al. 2019; Davidesco et al. 2019; Dikker et al. 2017). This initial research suggests that brain-to-brain synchrony is significant for learning, however, from the vantage point of the sociology of education there are two notable restrictions. The first is the use of lecture vs video to define styles of pedagogy which, while experimentally well-delineated, are not reflective of pedagogic forms in classrooms or teachers' movement between these in everyday professional practice. The second is the way that 'likeability' of and 'closeness' to teachers has been operationalised; relying on students' questionnaire reports and not differentiating between popularity and factors such as pedagogic approach, expertise or relationality which would be foregrounded by education research.

Encountering transdisciplinary research in education: Synchrony in learning

Building on this rich cross-disciplinary body of research, our team is developing collaborative transdisciplinary research into the biosocial influences on learning amongst children in classroom settings in which we are mobilising synchrony to examine social, relational, pedagogic, neural and biochemical processes involved in learning amongst children, as well as the interplay of these.

Transdisciplinary methodology

In this work we are informed by Lenz Taguchi's assertion that 'neuro-education' (or in our case 'neuro-bio-education') should not be pursued as a new 'trans-discipline' but that an

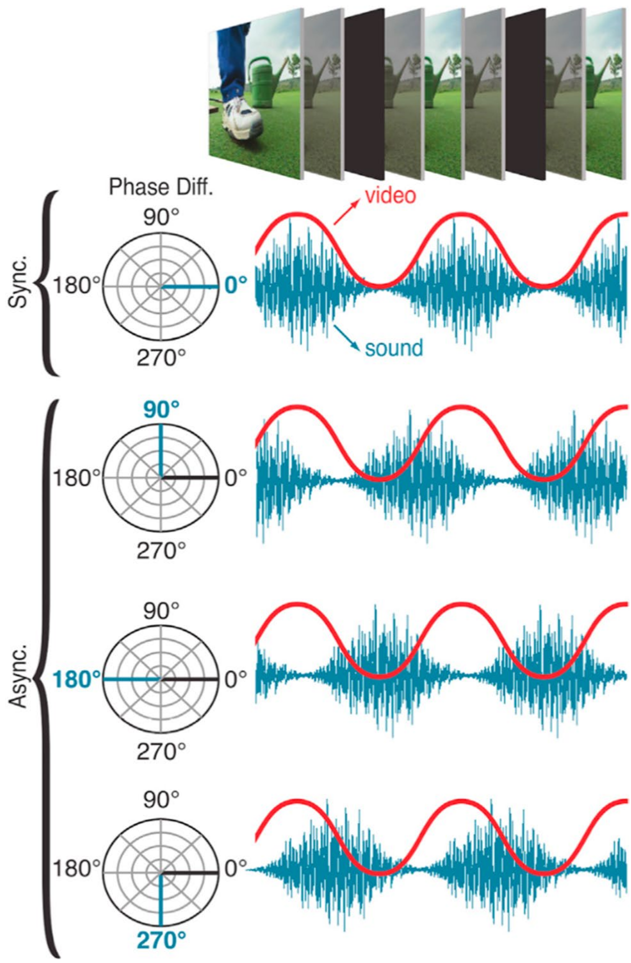

Figure 1. Depiction of the Experimental Paradigm: Sinusoidally flickering visual (red) and auditory (blue) stimuli are presented either in synchrony or at 90-degree, 180-degree, or 270-degree phase offset. From: Clouter, Shapiro and Hanslymayr 2017.

open-ended trans-disciplinarity should be maintained. We draw on Barad and Deleuze to remain alert to the ways that phenomena are produced through the entanglements and intra-actions of multiple forces—including social, pedagogic, neural and biological. This suggests we pursue learning as a phenomenon that is multifaceted and in-process. Our approach accepts Wilson's (2015) analysis that such work is disruptive of disciplinary knowledge and methodologies, a disruption that can be intellectually discomforting and mean that transdisciplinary is not always readily maintained—we each maintain our 'home' disciplinary commitments and slide in and out of our disciplinary knowledges and norms. Catherine Malabou's (2009) *Changing Difference* suggests that such encounters between knowledge domains are likely to lead to the 'metamorphosis' of concepts. In our case, encounters between sociology of education, wider education studies, neuroscience and biochemistry that are orientated towards transdisciplinarity have the potential to transform our conception of what learning is and might be.

Our transdisciplinary working, then, is in terms of the knowledge frameworks that underpin our thinking and our enquiry, the questions we ask, our methodology, research design, and analytic approach, and, ultimately, the factors that we understand to be important and the sorts of approaches to education that we might go on advocate. We are constantly caught in these trans-disciplinary processes, moving between conceptualisations and methods which themselves shift in the process. Rather than pursuing a new transdiscipline—a new field, a noun, a name for a known thing, we engage in transdisciplinarity as in-process, as metamorphosis (Malabou 2009) or even a queering—a doing, a verb, *transdisciplining*.

This brings us to a set of shared values and concerns which, in incorporating concerns and insights from across our disciplines, also transform the questions we ask:

1. What are the key neural, biochemical, pedagogic and relational processes involved in learning, and what is their interplay as these are produced through and exert influence on pedagogies, relationships and learning inside classrooms?

   And

2. How do these neural, biochemical, pedagogic and relational processes of learning synchronise independently and in an integrated manner as a function of the learning context?

These questions do not resemble the questions usually asked by any of our disciplines, even at their edges. Rather they suggest concerns and approaches transformed by the encounter. This work is in its infancy and has been paused by global school and university closures; at the time of writing we do not have sufficient sets of sociological, EEG (electroencephalographic) and biochemical data to present emerging trends here, but we are able to discuss conceptual and methodological transformations already underway.

Method

Deploying the lens of 'synchrony' to articulate our disciplines, we are pursuing three inter-related areas of study: 1. *Pedagogic approaches and relations*, using ethnography of classroom practices and relations to map the extent to which particular sorts of approaches and teacher-student and student-student relations relationships align or 'synchronise'; 2. *Brain* *oscillations*, using wireless EEG (electroencephalography) with learners in classrooms to map the extent and directionality of synchronisation of brain activity across learners, and between learners and teachers; and 3. *Biochemical/metabolic processes* using mobile mass spectrometry to generate biochemical profiles using volatile organic compounds in learners' and teachers' exhaled breath. In the demonstration experiment we discuss below, we focus on the entanglement of the first and second of these.

We draw on the basic neuroscience of Clouter et al. (2017) and replicate and extend the work of the Dikker lab to establish our EEG brain-to-brain synchrony experimental procedure. The concept of brain-to-brain synchrony in learning is integrated with nuanced concepts of pedagogy and relationality in learning. This allows us to think in terms of the pedagogic device (Bernstein and Solomon 1999; Ivinson 2012) to drill down into pedagogic approaches and relations, what it means for a teacher to be 'liked', and whether this is pertinent or not to either individual oscillation synchrony, brain-to-brain synchrony, or children's learning. Yet to be added to this experimental set-up in the collection biochemical profiles to augment our ethnographic work on feeling in the classroom (see below).

Experimental procedure: brain-to-brain synchrony

In order to test and refine our procedure, we undertook a series of pilot experiments in the Intelligent Classroom at the National Centre for Research in Learning Science at Southeast University (SEU), Nanjing. This 'intelligent classroom' has been equipped with high specification, multi-camera video recording facilities as well as high capacity power supply and wireless facilities. Volunteer students were recruited from the SEU campus to participate in the pilot experimental lessons which were delivered by one of us (Leng) in the field of physics (described here), and a volunteer professor of Chinese poetry.

Subjects: 8 volunteer students age 22–25 with similar backgrounds from the school of biological science and medical engineering at SEU joined the lesson.

Equipment: During the lesson, EEG activity of all 8 students was recorded using *eegoTM(ANT Neuro company)* (dense array wired EEG). The eye-gaze of 3 students was recorded using eye-tracking system (*Tobii pro X3–120* and *Tobii Glasses 2* from *Tobii company*). The lesson was recorded using high-resolution video cameras and observed by an ethnographer.

Experiment: During this pilot lesson we simulated 4 common ways that university teachers use to help students grasp the solutions to specific physics problems: classroom demonstration; mathematical model (solution 1); physical model (solution 2); and equipment operation. The content of the lesson was about two simple harmonic motions (SHMs). The goal of the pilot was to test equipment and experimental lesson design. In order for us to begin to utilise EEG and eye-tracking data of this sort in analysis, a data set comprised of data from the same students over multiple lesson, and multiple student sets will be necessary.

Set-up: A team of volunteer SEU M-level and doctoral students helped subjects fit the *eegoTM* and *Tobii Glasses 2*. 20 minutes was allowed in the protocol for this, but in effect it took significantly longer, confirming our consideration of more expensive sparse array *emotivTM* wireless EEG headsets. Once fitted, baseline measurements were taken by participants sitting at rest facing forward for 2 minutes and in facing pairs for 2 minutes.

Pilot lesson plan: the lesson proceeded with: a 2 minute classroom demonstration by the teacher; a lecture by the teacher divided into three problem chunks, each subdivided into concept introduction, solution 1 and solution 2 including teacher Q&A and student questioning; student operation of equipment; and closing with post-class baselines as at set-up.

Brain-to-brain synchrony in learning, pilot 1

Intelligent Classroom, Southeast University, Nanjing, China.

An almost-ordinary looking university seminar room. Smart board and chalk board at the front, rows of desks facing the boards, a wall of windows, a door front and back into the corridor. But the room is not-quite-ordinary—it has eight small domes of blue glass mounted at intervals across the ceiling—each sheltering a camera that is capturing video footage from multiple positions in the room. The desks are not-quite ordinary—single-seater but oversized, making space for a Perspex screen standing across-ways a third of the way along each desk. Behind it, obscured from the direct view of anyone seated at the desk, is a laptop and on the laptop screen a map of an EEG cap and 32 channel pick-up points.

The student-researchers are not-quite ordinary either. Each is part of a duo. A sitter, wearing a neon pink and black panelled EEG cap, 32 white button-like electrode pick-ups spaced across its surface, cable flowing down the sitters back like a thick black braid and connecting into the screened-off laptop. And a stander, without a cap but with a large clear syringe in hand, its nozzle fitted into a small opening in the centre of each white button, wiggling to aid clear gel pump through button, cap and hair until the gel conducts electric current from the scalp. The corresponding button on the laptop map changes from white to yellow to green. It is a drawn out process; button refuses syringe, hair refuses gel, gel refuses conduction, laptop display buttons refuse to change colour, or change and change back again. Observers wander around the room, curious, waiting, anticipating. Once sitter-scalp-gel-cap-cable-laptop connections are ensured, standers and observers retreat to the back of the classroom. On the front wall a small monitor cut into eight panes displays the video being captured from around the room.

Before the lesson can begin baseline EEG readings must be taken. An assistant at a table at the back of the room calls out, the room falls silent and the sitters all sit still and look forward. Two minutes pass slowly. The assistant calls out again. The standing part of each duo moves forward quickly, the sitter rises gently and the stander carefully rotates their chair a quarter turn, forearm supporting black cables while the sitter lowers themselves onto the sideways chair. The assistant calls out again. The now-facing sitters remain still and face forward, some looking into the face of the sitter opposite, other eyes glance away, or gaze instead into the space by the side of the sitter they are facing. Another two minutes. The assistant calls out again, the standers move forward and reverse the process of moving the chairs and sitters.

The lesson begins. It is a physics lesson on oscillations and these are Engineering students. The lecturer stands at the front of the room holding out a locket on a long chain, allowing it to swing in a sturdy arch. The lesson proceeds through a lecture-style account of the mathematics of oscillation. The Lecture is offered in Mandarin and the maths on the screen demands a substantial foundation.

Sitter-learners watch, listen, attend, some with straight backs, some with chins in hands, some with pens poised. The Lecturer moves across the front of the classroom space and between the first row of tables, she smiles, nods as she explains, sometimes addressing her account to a specific sitter-learner and sometimes to the class as a whole. The pink-black caps with their gel and buttons and cables encircle head and chin, perhaps tight, perhaps hot, perhaps overwhelming or perhaps by now filtered out of awareness.

A sitter-learner half-raises a hand and gently interrupts the Lecturer with a question. The Lecturer approaches the questioner with a smiling nod, asks something back, confers, responds, before turning back to address the whole class.

The lecture concludes and the sitter-learners are directed to a practical pairs activity. Again, not-quite ordinary—again, the standers move forward to relocate chairs, cables, sitters. A pair of electronic devices is deposited on the table between two sitter-learners who are again face to face. Dials are turned and green lines being to emerges on small monitors. In several of these pairs one sitter-learner reaches out to the equipment and moves from dial to dial making green lines begin to dance, while the other watches. Exchanges begin between the duos. Some smiles and small laughter. More exchanges, more interface with dials. More green lines dancing, becoming circles, beginning to oscillate. More smiles.

The Lecturer calls the sitter-learners back. Again standers more forward to relocate chairs and cables and sitters. The assistant calls out, another two minutes of silence as sitter look to the front. And two minutes as the sitters look face to face. And then it is done. Velcro is pulled apart under chins, pink and black caps are unpeeled from heads to reveal messed hair dotted with remains of glistening gel. Conversation and smiles. A relaxation. An accomplishment. I wonder about the synchrony of the demonstration.

Youdell Fieldnotes, 10/10/2019.

For a Sociology of Education reader this ‘intelligent classroom’ at Southeast University in Nanjing, China crowded with volunteer researchers and with students bedecked in striped

EEG caps and wired to nearby laptops while attending to a physics lesson may appear strange, at some distance from the rhythms and practices of an actual classroom, either in Nanjing or elsewhere. Indeed, our pilot underscores the demand to either smooth out the intrusion of the experimental equipment and team into the life of the classroom, and/or realise in practice the Baradian observation of the infolding of the apparatus within both the experiment and in the making of the phenomenon under study. It is clear that neither 'student' nor 'learning' will exist in 'natural' state in our transdisciplinary work. Also strange is the presence in this classroom of a (UK) sociologist of education (Youdell (alongside Shapiro, Sun and Leng)—not just as a critical education ethnographer but also as a leading member of the scientific team which conceived and orchestrated this experiment. This is not sociology of education or of science. Nor is this regular neuroscience—taken out of the laboratory setting and without finely controlled stimuli and response measurement, cognitive neuroscience is pushed to become something else as it is practiced by this transdisciplinary team. Likewise, researcher/subject/observer boundaries are porous, as volunteer students become engrossed in experiment set-up, and ethnographer (Youdell) and neuroscientist (Shapiro) struggle to understand the data generated by the methods of the other and then to fathom how these will be put into generative dialogue.

Yet our folding together of ethnographic observation and measurement of brain-to-brain synchrony offer a new way of capturing the relationality and affectivity of the pedagogic encounter and of learning. This ethnographic account of a pilot experimental lesson begins to suggest how the sociological and pedagogic investigation of classroom practices and relationships might be folded into investigation of learning relationships and potentially learning itself through synchrony, transforming the work that we do and the disciplines from which we work. We have not yet been able to extend this transdisciplinary investigation of learning further by layering in biochemical research which generates biochemical profiles and so accesses the biomolecular processes of metabolism. As we move on to do this we aim to capture a new dimension of the affective and emotional aspects of learning.

Critical education scholars have called for the reinstatement of emotion as a legitimate and important aspect of the classroom and of learning (Kenway & Youdell 2011) and the connection to embodied and social affectivities (Hickey-Moody 2014). In neuroscience there is active investigation of the relationship between emotion and learning investigating a range of specific associations and mechanism including emotional regulation and working memory; whether early life stress impacts memory; whether emotion impacts working memory, item memory or memory consolidation; and whether negative emotion impacts memory.

As some of us have discussed elsewhere (Youdell and Lindley 2018; Youdell, Harwood, and Lindley 2018), research in biochemistry has used measurement of Volatile Organic Compounds in exhaled breath to generate biochemical profiles that are indicative of metabolic processes within individual bodies and the extent of alignment—or synchrony—in these profiles across subjects sharing an experience. This has demonstrated emotional synchrony amongst audience members in the real life setting of the cinema during film screening and allowed the biochemical profiles of a range of emotional states to be mapped using mass spectrometry (Williams et al. 2016). Similar methods have been deployed in relation to education assessment, where consistent emotional responses have been found across university students undertaking a maths test in a laboratory setting (Turner et al. 2013). This body of research demonstrates biochemical processes at both the individual and collective level and suggests that these will be aligned to pedagogic experiences. These new approaches have so far not been used in classrooms and it is our intention to incorporate the investigation of synchrony of metabolic processes amongst learners, and between learners and educators, into our wider investigation of the influences on learning, enabling us to examine individual and collective affective responses to particular pedagogic approaches and relations.

Metamorphosis—Trans-disciplining

Even at this early stage of our research, and with a key component of our transdisciplinary method still to be added, we can see that our central concept, learning, is undergoing metamorphosis. Learning is no longer one of: acquisition of knowledge and skills and the capacity to use these; pedagogic approaches, materials relations; institutional structures, systems and practices; engagement and experience in the classroom; the identifications of students and teachers; modes of recognition and misrecognition; feelings flowing through learning encounters and circulating in classrooms; morphological and functional connectivities of the synapses that form neural circuits; cognitive capacities of attention, memory formation and retrieval; brain wave oscillations; metabolic pathways within cells; biochemical movements across membranes. Rather than struggle to determine which of these (or other) conceptualisations should define learning, our research is challenging us to understand learning as a phenomenon that is produced through the intra-action of these, as a multiplicity of processes generated in the 'radical exteriority' that de Freitas speaks about when she describes learning as 'profoundly relational and materially distributed' (de Freitas 2018, ibid).

It is important to note as we consider these transdisciplinary encounters and their challenges and potentialities that policy makers and educators are asking for new knowledge that needs these collaborations to be answered. Responding to the policy and practitioner enthusiasm for education neuroscience, equivocal early findings and concerns about the fidelity of interventions to the science, the UK Educational Endowment Foundation (EEF) has recently funded a systematic review of cognitive science in education (Shapiro and Youdell are co-investigators) that is using a tightly delimited protocol to assess education interventions as well as the underpinning neuroscience and their fidelity to this. Furthermore, UNESCO's *Futures of Education* programme (UNESCO 2020) has commissioned an International Science and Evidence in Education Assessment through its permanent education institution the Mahatma Gandhi Institute of Education for Peace and Sustainable Development (MGIEP) (MGIEP 2020), of which one of us (Youdell) is a Co-Chair. In the brief for this assessment neuroscience and the science of learning are foregrounded strongly. Further examples could be offered. We are keen that sociology of education is a central part of these discussions.

We hope that our transdisciplinary approach is part of a creative 'experimentation' (de Freitas 2018) and 'reconfiguring' (Aronsson and Lenz Taguchi 2018) that produces new understandings of learning that enable policy makers, school leaders and educators to think in new ways about their approaches to education, potentially transforming how we organise the settings in which children learn, the pedagogies used to facilitate learning, and the kinds of emotional atmospheres and relationships for learning that we engender.

This leaves us with the question of whether our collaborative transdisciplinary critical biosocial research continues to be usefully conceived of as Sociology of Education. We suggest that sociological theory, methodology and methods remain crucially important for generating critical and transformative understandings of education, but that the encounter of these with the knowledges and methods from the biosciences is transformative. Likewise, biosciences that recognise the importance of environmental factors need a deep engagement with sociological knowledge and method. Ultimately, we suggest that single disciplines as we have come to know them as a bodies of knowledges, concepts and methods, may no longer have traction for understanding complex contemporary questions.

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