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Opinion paper

Using collaborative action research to resolve practical and philosophical challenges in educational neuroscience

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A R T I C L E I N F O

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A B S T R A C T

Background: Researchers routinely cite neuromyths and neurorealism as barriers preventing teachers from effectively applying brain research to practice. A primary goal within educational neuroscience (EN), is to provide teachers with professional development that allows them to overcome these barriers and gain agency in developing the field. Yet, the EN literature does not provide a tangible framework for developing teachers' philosophical perspectives regarding neuroscience in education.

Purpose: Here, we review the history of teacher neuroscience professional development and identify challenges in developing EN teacher learning programs. Next, we present ‘learning study’, a form of collaborative action research, as a framework for addressing these challenges.

Conclusion: We highlight how learning study could be used as an appropriate model for exploring future classroom applications of theoretical neuroscience.

1. Introduction

As cognitive neuroscience continues to develop, brain research has a growing list of commercial applications. However, before adopting “brain-based” strategies and using them to guide professional practice, we need to carefully evaluate the practical and philosophical challenges inherent in applying neuroscience to industry. Perhaps nowhere is this more crystallized than in education, where teachers routinely adopt instructional strategies based on misconstrued or over-extrapolated neuroscience discoveries in their attempts to improve teaching and learning [1,2]. In fact, how to facilitate teachers’ practical use of neuroscience has become a focal question within the field of *Educational Neuroscience* (EN; taken here to include *Mind, Brain and Education, Brain and Education* and *Neuroeducation*) [2–5]. In this review, we first locate the issue of teacher neuroscience-training within EN. We then describe practical and philosophical challenges in EN that must be overcome in order to build an effective teacher neuroscience professional development program. Finally, we offer the learning study, a collaborative action research framework, as a model for surmounting challenges associated with teacher neuroscience education and professional development. We propose that learning study offers a comprehensive, theory-guided approach to classroom research, which could serve as the foundation for future EN applications.

2. Neuroscience in education

The 1990s were dubbed “the decade of the brain” [6]. It was during this time that commercial groups recognized the growing public interest in neuroscience and identified education as a professional sector wherein brain research had real world applications [7]. A “brain-based industry” arose rapidly, marketing programs to educators that claimed to use neuroscience to improve teaching and learning [8]. Neuroscience appealed to teachers for all of the same reasons it appealed to the general public but its ability to inform practice gave it immediacy in education. The logic was simple; the better teachers understood the brain, the better they could promote learning in their students. Quickly, administrators and teachers looking to stay on the “cutting edge” of research, began adopting programs like *Brain Gym*□ and the visual-audio-kinesthetic model [9,10]. Unfortunately, as educational researchers caught up to the “brain-based” craze, they found that these programs were often predicated on false or largely over-extrapolated beliefs about brain function that the researchers dubbed “neuromyths”' [7,9,11]. For example, the idea that a child's neurological predispositions dictate their learning style to be either visual, auditory, or kinaesthetic persists in education today, even though the efficacy of ‘learning style’ teaching models has been rigorously debunked [9,12].

At roughly the same time that educational researchers were

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questioning the effectiveness of brain-based programs [11], cognitive psychologists were questioning whether or not neuroscience was of any value at all to education. Bruer [13], in his seminal paper that accused neuroscience in education as being "a bridge too far", argued that neuroscience had little purpose in education other than to reify well-established theories in cognitive psychology (what he saw as the basic science of learning). This criticism is not unique to education. Neurorealism is a "…phenomenon in popular science news wherein brain research uncritically validates or invalidates the "realness" of particular beliefs or practices." [p. 189, 14].

In education, Bruer [13,15] was concerned that neurorealism was causing teachers to uncritically accept brain-based interventions when approaching educational issues and ignore decades of extremely rigorous research in cognitive psychology. Moreover, he argued that neuroscientists still required cognitive psychology to play an intermediary role in the development of educational interventions. This is because neuroscience studies aiming to elucidate and remediate cognitive deficits (e.g., dyslexia) rely on cognitive models, established through years of psychological and behavioural research [15].

Bruer's [13] critique spawned the field of EN, which, from a reading of the literature, aims to resolve two main questions. The first is to determine whether or not neuroscience can reasonably address current problems in education [13,16,17]. The second is determining how to introduce educators to neuroscience; in other words, how to build teachers' capacity to meaningfully apply brain research to their teaching practice through neuroscience-related professional development (PD) opportunities [4,18]. With respect to the former, there is now a growing body of literature to demonstrate that neuroscience provides novel insights about the nature of and approach to educational issues, far beyond what cognitive psychology alone can glean [19–23]. For instance, oscillatory entrainment studies in dyslexic and control subjects use EEG to observe how various brain waves attend to discrete phonological features within speech signals [19,24; Fig. 1]. Such studies provide support for a revised cognitive model of auditory word recognition and the development of novel educational interventions to treat dyslexia.

It is difficult to argue at this point that there is no place for neuroscience in education. In his recent document co-citation analysis, Bruer [25] acknowledges that among articles debating the "...merits and demerits, promise, and pitfalls of attempting to apply neuroscientific research to education" (p. 7), most authors agree that neuroscience can positively impact education. However, to realize its potential, EN needs to address the second question—how to provide an adequate and consistent teacher PD framework?

Within the literature, many authors argue that teachers should have a primary role in directing EN research [4,5,20,26–28]. In fact, in a paper from the Task Force on the Future of Educational Neuroscience, Fischer et al. [5] state:

> The ultimate agent of change in the educational system is the teacher, and so the development of infrastructures that bring teachers and researchers together is an important goal (p. 74).

Skeptics of EN, however, suggest that the damage done by persistent neuromyths and neurorealism in education is too vast for any teacher development program to overcome. Bowers [29], for instance, asserts that:

> Rather than introducing neuroscience to teacher training it would be better to just avoid all forms of instruction that are motivated by neuroscience (p. 604).

Bower's argument can be succinctly summarised as follows: if the strongest proponents of EN are themselves propagating the neuromyths and neurorealism they set out to dispel, then the field is critically flawed and holds no value for education.

Yet, there is resounding evidence that neuroscience can meaningfully contribute to education (see: [4,19,20,28,30–34]) and, thus, the community must reject overly pessimistic appraisals of neuroscience PD programs. The most effective solution for eliminating pervasive neuromyths and neurorealism among teachers is not to cease discussing neuroscience; rather it is to thoughtfully consider the challenges that allow these issues to persist and correct them [35]. The next section sets criteria for the development of effective neuroscience PD.

3. Criteria for successful neuroscience-framed teacher development

Before discussing the practical and philosophical limitations of neuroscience-focused teacher professional development, there needs to be clear criteria for what PD programs should achieve. First, they should allow teachers to accurately interpret neuroscience resources, including academic papers, conference proceedings, popular science texts, and educational literature [3,4,30]. Understanding the language, technologies, and research methods in neuroscience allows teachers to distinguish academically rigorous content from conjecture. Second, PD should allow teachers to apply this knowledge to relevant contexts (i.e., the classroom) in order to assess whether or not neuroscience information can improve student learning and their effectiveness as educators [4,5]. Finally, PD should permit teachers to develop their own theories about educational applications of neuroscience and feed these insights back into the field of EN and educational institutions [3,5]. Thus, teachers need to feel comfortable developing and presenting theoretical work relative to their own pedagogies. After setting explicit criteria for what neuroscience PD should achieve, it is now possible to review the practical challenges in designing such programs.

4. Challenges inherent in teacher neuroscience professional development

4.1. Practical challenges in structuring educational neuroscience PD

The first obstacle is building a collaborative, multi-disciplinary infrastructure that enables teachers to interpret, conduct, and theorize about neuroscience. The purpose of such an infrastructure is not to have teachers become neuroscientists but, rather, to provide them with a level of neuroscience fluency that allows them to inform and direct EN research. A traditional, one-off teacher PD model does not provide teachers with the time they need to develop their neuroscience literacy nor the guidance they require to experiment with and reflect on neuroscience-informed pedagogies. Building such capabilities among teachers requires an integrative, long-term approach to teacher PD [28,32,33,36–39]. To address this need, the *Mind, Brain and Education* (MBE) community has initiated a research schools network, similar to research hospitals, that brings educational practitioners and neuroscientists together to tackle salient problems in education [37,40–42].

A key operating feature of these schools is the neuroeducator or educational engineer [4,37,43–45]. These are individuals who are trained in various disciplines–including education, cognitive psychology, neuroscience, and genetics–and, among other duties, facilitate neuroscience teacher-training. Even though authors usually describe this training infrastructure as including research schools and neuroeducators [5,37], neuroeducators can act independently within districts or independent schools to guide teachers' development. The presence of school-based facilitators means that teachers are never left in isolation to interpret technical information or build professional competencies. Collaborating with neuroeducators, therefore, means that teachers are much less likely to fall prey to neuromyths or neurorealism.

We agree that using neuroeducators to direct teacher-training (either in research schools or as independent contractors) can be a productive means of PD that gives teachers agency in the EN community. However, this is contingent upon the use of an appropriate PD framework, which represents another practical limitation. As universities like

Harvard and Cambridge are establishing MBE degree programs designed to prepare the first generation of neuroeducators [35], the teacher professional development framework that MBE candidates eventually will use to guide their interactions with teachers remains vague. In fact, a detailed model describing how exactly neuroeducators will facilitate teachers' understanding, applications, and theorizing about neuroscience appears to be absent from the literature, yet it is an essential aspect of the neuroscience PD infrastructure. To exacerbate the gap in knowledge and practice, these neuroeducators may inevitably fall back on traditional, one-off PD formats that have been commonly employed, despite their ineffectiveness [36].

In 2010, The Task Force on the Future of Educational Neuroscience broadly recommended using an action research framework within research schools networks to root neuroscience inquiries in educationally relevant questions and test applications of that research in practical settings [5]. Generally, teacher action research is a form of practitioner-driven classroom research designed to solve specific problems or overcome specific challenges in education. Ostensibly, neuroeducators could use action research to help teachers' develop their neuroscience literacy, as its aims are well-aligned to those of EN. For example, Carr and Kemmis (p. 165, [46]) state that action research "aims at improvement in three areas: firstly, the improvement of a *practice;* secondly, the improvement of the *understanding* of the practice by its practitioners; and thirdly, the improvement of the *situation* in which the practice takes place." Moreover, Pine (p. 30, [47]) asserts that "Action research empowers teachers to own professional knowledge because teachers— through the process of action inquiry—conceptualize and create knowledge, interact around knowledge, transform knowledge, and apply knowledge" (see also [48]). These descriptions of action research are very much in line with the Task Force on the Future of Educational Neuroscience's [5] view that improving teachers' neuroscience literacy could improve practice and help teachers develop the knowledge they require to aid researchers in fruitfully directing the field of EN.

However, the Task Force on the Future of Educational Neuroscience (2010) did not go as far as proposing a specific action research model (of which there are many). They also did not explore potential limitations of action research as a model for neuroscience PD or indicate how such a framework might complement the use of neuroeducators. The suggestion to use action research, in fact, appears to be a response to an earlier article by Kuriloff et al. [49], who used *participatory* action research to form collaborations between universities and schools in addressing social factors (e.g., gender, race, class) associated with variable student performance. Before employing a practical framework, such as action research, to guide teachers' neuroscience PD, one should consider whether that framework adequately achieves the goals set out in Section 3 (i.e. to facilitate teachers' understanding, application, and theorizing of neuroscience with respect to education).

John Elliot, a leader in action research, recently articulated his concerns over forms of action research that perpetuate a behavioural objectives model of curriculum design [50]. That is, action research that leads to teachers holding an instrumentalist view of their teaching actions (i.e. teaching actions to produce measurable student behavioural outcomes). Within such a model, it becomes easy for teachers' foci to be directed disproportionately toward identifying 'actions' or teaching strategies that bring about desired behavioural outcomes among students. Rather, Elliot [50] asserts, teachers should consider how their actions (means) interact with their intended learning object (ends) to help them articulate the broader educational aims to which they are committed (this is known as the process view of curriculum design). According to the author, this can be brought about through reflective pedagogical practices that take into consideration students' learning experiences. Such practices would shape the learning object, the ways by which it could be achieved, and the action research process. In Elliot's [50] own words:

> The relationship between ends and means in the 'process model' is significantly different from the 'behavioural objectives model'. In the latter, the ends can be defined independently of the means chosen to bring them about. In the former, the aims and principles are defined by the actions taken to realise them. One becomes clearer about the ends by discerning the appropriate means of realising them in action. Ends and means are joint objects of reflection in teachers' action research (p. 5).

With respect to teachers' neuroscience PD then, action research that propagates a behavioural objectives model of curriculum design, would direct teachers' attention to practical applications of brain research that can produce desired behavioural outcomes among students. That is, teachers' focus is explicitly on measurable, behavioural outcomes. This leads to teachers viewing neuroscience as a set of prescriptive, fixed principles that can be formulaically applied to their practice to improve teaching and learning (i.e. applying neuroscience principle 'A' leads to student behavioural outcome 'B'). Relative to our criteria for successful teacher neuroscience PD in Section 3, a behavioural objectives model at best allows teachers to understand and apply neuroscience principles. It falls short, however, of allowing teachers to theorize about how and when they can apply these principles to the learning process in a way that is consistent with student learning experiences (rather than outcomes). It also fails to provide teachers with opportunities to articulate their teaching intentions and realise the moral aims to which they are committed. Thus, teachers' agency within EN is limited.

On the other hand, a process model of action research promotes teachers' theoretical understanding of how brain research can inform their teaching actions in a way that accommodates student learning and helps realise their broader educational aims. In such a model, teachers are continually challenged to reconcile their actions and teaching intentions with their developing understanding of students' learning as informed by neuroscience. Through the teachers' own classroom research, as is promoted via the process model, teachers could theorise about which aspects of neuroscience usefully inform their practice and which are of limited value, at least in the educational context they are examining. As a result, teachers improve their ability to understand and apply theoretical neuroscience, where they develop theoretical coherence in their understandings of teaching and learning [51]. Their insights also help direct the way that brain research is applied in future educational contexts. Hopefully, it is clear that improved student outcomes, although a likely goal of this type of action research, is not premised on simplistic attributions of learning to pedagogical acts, but rather, reflective teaching processes that integrate students' classroom experiences with the teacher's approach to planning and teaching instruction. [48]. To summarize, action research in and of itself is not the answer for establishing a suitable and consistent framework for neuroscience PD. Importantly, the chosen framework needs to promote a process, rather than a behavioural objectives view, of curriculum design.

Section 5 demonstrates that 'learning study', as a form of collaborative teacher action research [48], comprehensively addresses the challenges raised in this section and is uniquely positioned to serve as the basic model for teacher neuroscience PD. The following Sections (4.2 and 4.3, review philosophical challenges for structuring neuroscience PD that have been raised, but not overcome, in the extant EN literature.

4. 2. Ontological challenges in educational neuroscience

This section discusses the ontological positions held by neuroscientists (monist) and educationalists (dualist) in their broadest sense because an analysis of subordinate categories (e.g. substance vs. property dualism) is beyond the scope of this paper. Few scientists or teachers are likely to be strict monists or dualists. However, the arguments that arise from considering these extremes help bring into focus ontological issues that arise at the interface of neuroscience and education. Given the current structure of teacher education programs, the main philosophical challenge that neuroscience PD needs to overcome is bringing about ontological shifts in teachers' views of knowledge construction (i.e. learning). Teacher education programs and PD for practicing teachers, most often present teachers with constructivist theories of learning (e.g., Piaget and Vygotsky's theories of cognitive development) [52]. These theories are rooted in relativism and suggest that a learner's knowledge is a reflection of their unique environmental circumstances. These theories have or are perceived to have dualist underpinnings that ascribe the process of learning to an abstract human mind [53] and, as a result, stand in direct contrast to the monistic view of human cognition that neuroscience invokes and which is rooted in realism.

It is not our intention to infer here the philosophical predilections that Piaget or Vygotsky held in the development of their theories (but see [53]; plus [54], for further discussion). Rather, our aim is to highlight that the educational community broadly interprets constructivist theories as having dualist underpinnings, which inclines teachers to view knowledge construction in a way that is fundamentally opposed to the monistic view held by neuroscientists. This is important because the way teachers understand knowledge construction dictates the actions they take to realize their educational aims. It may be that pedagogies arising from dualistic and monistic views of human learning are remarkably similar; however, not addressing ontological disparities explicitly during teacher neuroscience PD allows for logical inconsistencies that inhibit teachers' base understanding of neuroscience. For example, a dualist view maintains a strict divide between mind and brain. That is, an understanding of brain processes is not required for explanations of human cognition and *vice-versa* [55]. This stance, however, negates a wide body of empirical evidence that suggests the disruption of discrete brain networks (through injury or experimental inhibition) influences cognitive abilities [56–59]. Such evidence suggests that many aspects of cognition, such as learning, have neural underpinnings that make the brain an appropriate level of analysis [55].

Historically, a dualist view of knowledge construction has allowed teachers also to assert that cognitive deficits with a neurological basis are beyond their professional capacity to address and belong in the realm of medical science (see Howard-Jones' [55] discussion of ADHD, p. 370). Yet, an understanding of their underlying biology has improved our understanding of learning disorders (e.g., dyslexia), making clinical diagnoses more efficient and educational interventions possible [60]. Therefore, consolidating brain and mind can result in novel pedagogies that improve teaching and learning. As such, a primary focus in teacher neuroscience PD should be to promote a view of knowledge construction that includes biological perspectives and allows teachers to develop theories about how these perspectives inform teaching and learning.

Of course, we are not and cannot argue for a strictly monistic view of knowledge construction in teacher neuroscience PD. While a monistic view of knowledge construction holds that all of human cognition can be explained at the level of the brain, neuroscience has not developed to a stage where one can reasonably dismiss the notion of mind [15,61]. As Davis [16] suggests, there is a propensity in neuroscience to infer biological bases for cognitive disorders where no such evidence exists. For example, in fMRI studies of ADHD, there are marked differences in brain activity during cognitive tasks between patients with ADHD and normal patients. While this alludes to some fundamental difference in neural function between the two groups that can explain their disparities during task completion, there is no concrete evidence to suggest why these between-group variations exist [62,63]. It could be due to group differences in (a) the expression of various neurotransmitters or neuromodulators, (b) neuronal density within brain regions of interest, (c) connectivity between these brain regions, or (d) task-specific activation thresholds of auxiliary brain regions, to name a few [64]. Without knowing the underlying causes of differential brain activity, these studies do little to inform our understanding of cognitive deficits beyond what is known from behavioural experiments, let alone help guide educational practice.

Moreover, as Williams and Standish [65] *vis-a-vis* Bennett and Hacker [66] point out in their philosophical appraisal of neuroscience in education, monism often leads to cognitive abilities being ascribed to the brain rather than the individual. This type of mereological fallacy–as Hacker [66] puts it–is dangerous because it applies psychological predicates, like learning, to the brain rather than the individual. With respect to teaching, seeing the brain, rather than the individual, as being responsible for learning forgoes many environmental factors acting at the individual level to impact learning. For instance, the human brain *can* produce a near infinite number of behaviours that align with various social conventions; yet the behaviours a student *does* produce in a given social setting (e.g., the classroom) are the result of their experiences within that setting [65]. Thus, by considering the brain as the primary level of analysis, we lose something fundamental in our understanding of how students come to follow specific conventions, which leads to an impoverished view of human learning. There is no practical gain in making teachers choose between a dualist or monist view of knowledge construction. Neuroscience PD should provide teachers with a robust understanding of the issues arising from both ontological viewpoints so that they can theorize about EN in a way that meaningfully develops their practice and the field. By explicitly developing teachers' ontological perspectives on knowledge construction, neuroeducators can provide teachers with an awareness of philosophical issues that will allow the teachers to theorize about their practice in specific classroom settings and give them agency within EN.

4.3. Epistemological challenges in educational neuroscience

As well as developing their ontological perspectives, teachers need to be made aware of the epistemological issues that arise from using educational interventions built on neuroscience principles [67]. The primary epistemological concern regarding neuroscience PD is the incommensurable nature of positivism (science) and interpretivism (education) and the research methods they beget. Educational research, traditionally a social science, largely (though not exclusively) relies on interpretivist epistemologies [68]. For example, educational researchers often employ qualitative methods to consider distinct environmental factors (e.g. student composition, income levels, geography) with respect to concrete, local issues (e.g. differences in male and female test scores). Additionally, when these researchers accumulate enough case studies, they are able to develop broader theories based on identifiable trends in their data. Neuroscience, on the other hand, largely employs positivist epistemologies and quantitative methods to identify general relationships between brain morphology, activity or physiology and cognitive variables (e.g., memory, problem-solving, attention, affective disorders). Neuroscience researchers hypothesize causal relationships between variables of interest and run controlled, iterative experiments to isolate variables and reveal dependent relationships [69].

Thus, EN can be a challenging field because it attempts to: (a) merge two research programs that have discrete (and sometimes opposing) epistemological views (though note the development of neuro-constructivism [70]), and (b) use qualitative research methods to generate data about educational issues that might be explored using quantitative neuroscience techniques [18,55,71]. This merger leads to epistemological challenges that neuroeducators and teachers need to consider, most notably: What types of questions in education can we reasonably address with current neuroscience research methods? Similarly: Does neuroscience better explain a child's learning abilities beyond what we understand by simply studying behaviour directly? Hopefully, it is clear that as teachers start to consider such questions, they will develop their ability to critically evaluate which aspects of neuroscience best inform their practice. A robust teacher education and neuroscience PD program, therefore, would make teachers overtly aware of epistemological issues that arise from merging education with neuroscience. This would allow them to make their own value judgments about what aspects of neuroscience are worth pursuing.

5. Neuroscience-framed learning study

This section presents ‘learning study’ (LS) as an established PD model that can help teachers tackle the practical, ontological and epistemological issues raised earlier and facilitate teacher neuroscience development. LS is a variant of teacher *collaborative* action research [72], and broadly differs from *participatory* action research (compare with [45]) as the goal is not always emancipatory or socio-political in nature (see [73]). Rather, LS, as *collaborative* action research, emphasizes the importance of teachers collaborating to solve educational problems, which could include addressing student learning difficulties. The framework is used to help teachers develop their understandings of educational theories, with the pedagogical goals of increasing the quality of teaching and learning. Teachers, with the guidance of expert facilitators, then attempt to apply these theories to their pedagogies as part of their collaborative lesson planning, teaching and classroom research [74]. Within the context of EN, the approach could generally comprise of the phases listed in Table 1 [75,76].

LS addresses how one-off PD formats [36] exploring neuroscience often leave teachers to work in professional isolation without the benefit of experts to guide them (c.f., [5]). It emphasizes the importance of sustaining teachers’ participation and promoting learning through peer collaboration and collegial interaction [77]. Within the loci of teachers’ own classroom control, these critical features are coupled with opportunities for teachers to engage with their own theory-framed classroom research. This allows teachers to examine their collective understandings of the select theory, and concomitantly plan and test their theory-framed instructional practices in iterative cycles of teaching-reflection-refinement of lesson plans [78]—this is a distinguishing feature of LS [50,79]. LS, thus, provides an avenue for neuroscience to be introduced, examined and applied to concrete teaching situations. The localization and testing of neuroscience ideas within one's context deviates from common one-off models of teacher PD. As with the approach forwarded by Fischer and colleagues [5], LS is often supported by an external facilitator that could assume the role akin to that of a neuroeducator to guide teachers’ interpretations of neuroscience information.

Elliott [50] suggests that the strong theoretical underpinning of LS is critical in supporting teachers’ theorizing about their own practices through inquiry and reflection (see also: [78,80–82]). As part of this theoretical work, teachers attempt to collectively integrate neuroscience with existing curriculum and pedagogical practices, with students’ learning experiences serving as the point of departure and focus of the LS [69,70]. The goal is to enrich student learning, improve teaching practice, and promote teachers’ reflection on their pedagogies [69,74,79,80]. It also allows teachers to make judgments about how neuroscience knowledge is of value to classroom instruction, thus informing the field of EN. In this view, the teachers’ practical testing of neuroscience theories within actual classroom settings allow them to move beyond receiving neuroscience information that has been developed in highly artificial contexts [28]. Rather, the teachers could learn to design and apply neuroscience-informed pedagogies that consider contextual factors that shape human learning, as well as the naturalistic settings of the classroom where a complex array of factors could influence learning. Within this LS framework, teachers could develop a process view of learning and attending to larger educational goals (see also [50]). To our knowledge, there is one case of neuroscience-framed LS, where, through participation in the study, the teachers were reported to have developed understandings of the cognitive architecture underlying neural functions of learning and memory [86]. In the process of applying their own neuroscience-informed insights to instructional processes, the teachers developed theoretical coherence in teaching and learning, and were better able to articulate their pedagogical decisions.

Pertaining to the ontological and epistemological challenges raised in this paper, learning study provides teachers opportunities to examine and discuss how select educational theories are applied in classroom settings [69,79]. In other words, if and how neuroscience provides a gainful connection between teaching and learning is not assumed but tested through concrete lessons the teachers enact and evaluate as part of their collaborative classroom research [86]. Furthermore, throughout the learning study phases, such as when discussing the theories and planning their lessons, teachers are challenged to make their epistemological and ontological convictions explicit [75].

Several authors have reported on how LS promotes shifts in teachers’ conceptualizations of teaching and learning by raising awareness of their own beliefs and of testing these beliefs through theory-framed instruction [74,75,83–85]. Of importance is that these studies tackle teachers’ views of the nature of human learning, and thus provide a platform to examine their conceptions of the brain and knowledge construction [86]. Similarly, developing teachers’ neuroscience literacy requires teachers to understand and inquire into the nature of the scientific knowledge, including methodological processes and technological advancements. The potential of including this aspect in a LS discourse addresses the epistemological questions inherent within the use of neuroscience.

6. Conclusion

Neuroscience has and will continue to impact the ways educators view teaching and learning. Whether or not neuromyths and neurorealism continue to shape teachers’ understanding of neuroscience

Table 1
The following is a suggested sequence of learning study phases that a facilitator/researcher could use to introduce teachers to neuroscience (adapted from[75]). This framework can overcome the practical and philosophical challenges inherent in structuring teachers’ neuroscience professional development.

Phase	Description
1. Pre-study	An entrance interview where researchers/facilitators explore teacher's epistemological and ontological views of neuroscience (raised earlier), as well as beliefs about good teaching and the theories that the teacher uses to guide his or her practice.
2. Planning I	Teachers discuss and examine select neuroscience information as guided by the facilitator; resources could include neuroscience papers and notes (prepared by facilitators). Teachers also identify a topic and an object of learning [81] to which they can apply the working knowledge of educational neuroscience they have developed. Notably, this stage allows teachers to find logical connections between the primary neuroscience literature and their own teaching practice.
3. Planning II	Teachers collaboratively design a research lesson or series of lessons that incorporate their developing knowledge of neuroscience.
4. Research and reflection	Teachers teach the research lesson(s) and observe their colleagues enact similar lesson(s). Reflection takes the form of eliciting feedback from the group and researchers, where opportunities are provided to refine lesson plans and/or to re-teach the lessons.
5. Post study	Teachers undergo another interview or series of interviews that could serve as a platform for reflecting upon their learning. The phase also includes dissemination of the learning study results by researchers and teachers, which can take the form of school-based seminars, conference papers, or academic publications.

depends on the teacher education and PD we provide as they develop their perspectives on how brain research might influence classroom teaching. The programming requires deep consideration of not only infrastructure and practical barriers, but also philosophical challenges that exist at the level of teacher education and PD. LS offers an established, consistent PD framework that could potentially address these challenges and allows teachers to realize their role as critical agents in advancing the field of EN. By providing teachers with directed opportunities to explore, apply, and theorize about brain research with respect to their practice and student learning, we move toward a theory-guided approach to neuroscience in education. Finally, a standardized framework for teacher neuroscience PD facilitates the dissemination of vital research while providing directly relatable results in a variety of educational contexts. Such research could be used to examine the effectiveness of future neuroscience interventions.

Conflict of interest

Both authors have read and agree to the submitted version of this manuscript, titled "Using collaborative action research to resolve practical and philosophical challenges in educational neuroscience." We confirm that this manuscript is not under consideration for publication elsewhere and represents the original ideas of the authors, except where citations are provided. Figure 1 in this manuscript requires reprint permission from Sage Journals upon acceptance for publication. We have no conflicts of interest to report.

Ethics information

This article is a theoretical opinion piece and did not use animal or human subjects for the collection of empirical data. As such, this manuscript adheres to the ethical guidelines for publication in *Trends in Neuroscience and Education*.

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