**The Hard Problem of ‘Educational Neuroscience’**

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**Abstract**

Differing worldviews give interdisciplinary work value. However, these same differences are the primary hurdle to productive communication between disciplines. Here, we argue that philosophical issues of metaphysics and epistemology subserve many of the differences in language, methods and motivation that plague interdisciplinary fields like educational neuroscience. Researchers attempting interdisciplinary work may be unaware that issues of philosophy are intimately tied to the way research is performed and evaluated in different fields. As such, a lack of explicit discussion about these assumptions leads to many conflicts in interdisciplinary work that masquerade as more superficial issues. To illustrate, we investigate how philosophical assumptions about the mind (specifically the hard problem of consciousness and mind-body problem) may influence researchers in educational neuroscience. The methods employed by researchers in this field are shaped by their metaphysical beliefs, and arguments around these issues can threaten accepted disciplinary ontologies. Additionally, how a researcher understands reduction in the special sciences and how they place their colleagues in this ontology constrains the scope of interdisciplinary projects. In encouraging researchers to explicitly discuss the philosophical assumptions underlying their research we hope to alleviate some of the conflict and establish realistic expectations for collaborative projects.

*Keywords:*interdisciplinary; philosophy; science of learning; mind-body; translation

Interdisciplinary work is increasingly important and valued in academia. The questions of greatest practical importance today are rarely discipline-specific and can be investigated using many different methods. When considering questions that affect humanity broadly – such as those concerning health, international affairs, environment, education, or resources – the complex and systemic nature of these questions necessitates the ideas and methods from many different disciplines come together and develop comprehensive solutions. The possibility for the success of interdisciplinary work is evident from a growing body of publications and journals dedicated to combining two or more fields, such as *npj Science of Learning* (journal which pools research from neuroscience, psychology, and education in order to explore human learning), and the *World Review of Science, Technology, and Sustainable Development* (a journal which pools ideas from chemistry, economics, and urban development in order to explore sustainable development).

In this paper, we use the term “interdisciplinary” broadly; as that which involves sharing of information and frameworks specific to qualitatively different academic fields in an attempt to answer a common question. The most difficult and relevant instances of this to our discussion are cases of transdisciplinary projects where discipline specific knowledge must be synthesised and a new language and set of methodologies must be created as an integration of the relevant disciplines [1]. However, researchers engaging in all forms of multi-disciplinary collaboration (along the continuum from multidisciplinary, interdisciplinary to transdisciplinary practice) will benefit from the discussion herein.

Funding bodies recognize the importance of communication between disciplines in addressing complex problems and incentivise these endeavours by requiring researchers to work together for many competitive grant applications. The major funding bodies for science research in the USA and Australia, namely the National Institute for Health (NIH), National Health and Medical Research Council (NHMRC), and Australian Research Council (ARC), all encourage interdisciplinary research. In June 2016, out of a total of 1093 active grant calls for research at the NIH, 21.0% mentioned the word multidisciplinary, 13.9% mentioned the word interdisciplinary, 2.8% include the word cross-disciplinary, and 3.8% mentioned transdisciplinary research. In total, 31.5% of grant calls for the NIH included the terms cross-, multi-, inter-, or trans-disciplinary research (http://grants.nih.gov/Grants/guide/). Additionally, the ARC has a $10,000 prize awarded yearly to a successful interdisciplinary team (The Eureka Prize). Working together has become a lucrative business.

More importantly, interdisciplinary work is necessary for effectively translating “basic” research, which resides between experts and academics, to more practical applications relevant for policymakers, practitioners and the public. In order to make one’s research publically relevant, theories need to actively move beyond the simulated lab environments and into more ecologically valid social spheres. The NHMRC in Australia, for example, includes research translation into policy and practice as one of three factors used to prioritize funding of grant applications in health.

Despite its grand aims, successful interdisciplinary research still has its obstacles, and doing it successfully requires a reflective team willing to devote the time necessary to accommodate the values of the other disciplines and researchers. By virtue of coming from different perspectives, there will necessarily be disagreements and misunderstandings that require negotiation. This process is made worse through a lack of ‘brokers’ who can effectively translate from one disciplinary context to another [2]. Awareness of epistemological pluralism, or the idea that there are multiple valuable ways of ‘knowing’ that come from various disciplines, can help us negotiate and accommodate the methodological requirements of the various disciplines in working towards the same goal [3].

Philosophical bases for this plurality are often undiscussed in the context of a particular interdisciplinary project [4]. For example, medical researchers might assume positive realism, which claims that there is an epistemically accessible reality that can be empirically studied, and resort to hypothesis driven experimental research to objectively access knowledge about the question. On the other hand, humanities-based researchers are more likely to rely on a constructivist viewpoint, which holds that reality is relative to a time, place and perspective, and adopt qualitative methodologies which accept and invite subjective approaches [1]. In approaching one question, the realist approach may be seen as overly reductionist by the humanities researcher whilst the constructivist methods may be seen as confused and confounded by the medical researcher. Collaborating on a frame that both parties are satisfied with can be difficult.

Here, we argue that philosophical assumptions that differ between fields and individuals impact how research is conducted and contribute to conflicting approaches when attempting interdisciplinary projects. Further, we claim that specific beliefs about the way the world is and beliefs about the ways in which knowledge can be accessed (metaphysics and epistemology) trickle up from unconscious sources to change how research, the methods used in approaching a specific question and the motivations for performing research are interpreted and conveyed. We will use a specific example of an interdisciplinary field of research about educational neuroscience (otherwise referred to broadly as Science of Learning), which spans (at least explicitly) the disciplines of neuroscience, psychology and education. However, these issues are not specific to this case study, and an argument for this will be elaborated after we establish the relevance of philosophy to interdisciplinary discussions in this field. It is, perhaps, worth noting here that the aim of this exploration is not to provide concrete methods by which to bridge the gap between varied philosophies – it is merely to highlight the consequences differing beliefs may have on interdisciplinary work and suggest that an explicit discussion of these issues is warranted early in the translation process.

*What is the nature of interdisciplinarity in educational neuroscience?*

The Science of Learning (SoL) is an interdisciplinary field (also known as educational neuroscience; mind, brain and education; learning sciences, etc.), which is an effort to translate insights about the brain and mind to enhance practices in the classroom. As the organ of learning, the brain is an obvious place to search for answers about the biological bases for learning [5]. Questions about the viability of the field in developing successful educational interventions are under longstanding and heated debate [5-16] with laborious and detailed suggestions for successful collaboration from even the most fervent advocates of the integration.

Topics of relevance to this field range from molecular studies of mechanisms for long-term potentiation (the cellular mechanism for memory), to mouse models for reinforcement learning, human brain network analysis during simple perceptual tasks, psychological discrimination tasks, reaction time in complex reasoning tasks, emotional regulation, social psychology in the classroom, pedagogical evaluation and recommendations, and educational policy formulation and evaluation. Working between some of these fields is relatively straightforward. For example, moving from brain imaging studies of a perceptual task to psychological discrimination theories does not require a distal inference to be made. However, trying to integrate cellular mechanisms for memory with prescriptive policy recommendations is vastly more difficult. Anderson [17] referred to the possibility of making such distant inferences as a ‘seven orders of magnitude problem’. There is inherent difficulty in attempting to infer from a phenomenon that occurs in a small part of the brain over millisecond time periods to the education of a professional, for example, that takes many years and occurs in a complex social milieu [18]. The complexity of this translation task results in confusion and possible conflict stemming from differences in language, methods and motivation at each of the layers of interpretation between the brain and broader society. Ultimately, researchers in this area come together to better understand and promote learning, so improving communication amongst these disciplines will further this aim. Actively engaging in dialogue with the aim of uncovering philosophical bases for differences in research practice is one way to facilitate productive and empathetic communication.

***The Hard Problem of Consciousness***

*Issues of philosophy that matter to Educational Neuroscience*

To many researchers and empirical scientists, philosophy seems irrelevant and outdated [19]. To a philosopher, debates surrounding the nature of the mind have ancient origins (for instance in Plato’s *Phaedo*, or *Parmenides* [20]) but are alive and ongoing today [21-25]. Here, we will give background to some of the philosophical issues that are most relevant to the Science of Learning.

*The mind-body problem*

The mind-body problem is, in essence, a question about the relationship between what we normally call mental phenomena and physical phenomena. Here, mental phenomena will include thoughts, emotions and sensations like pain and hunger. By physical phenomena, we mean things made of matter that interact by physical laws. As Ludwig notes [23], there is no consensus amongst philosophers about the appropriate answer to this question. All of the solutions seem unacceptable for one reason or another. Throughout the years, many scholars have claimed to have “solved” this problem, some arguing for a “new” way of approaching it based on advancing scientific methods [26, 27], some claiming that there is no problem to solve [28], or that it can’t be solved and we should make our peace with it [29]. What is clear is that the discussion is ongoing but this is rarely recognised when studies examining the brain are interpreted for use by educators.

The mind-body problem can be characterized as a puzzle stemming from the inconsistency of four premises:

1) *Realism*: there are things that have mental properties;

2) *Conceptual Autonomy*: mental properties are irreducible to non-mental properties, and following, non-mental properties do not entail mental properties;

3) *Constituent explanatory sufficiency*: a description of something’s’ constituent parts and their interactions is sufficient for a complete description of the thing;

4) *Constituent non-mentalism*: basic constituents do not have mental properties [23].

Each of these premises is, *prima facie*, true. We constantly use mental states as explanations for our own behaviours and reasoning about the behaviours of others. Premise two is supported by the idea of a philosophical zombie – that is, it is conceivable that there is a being that acts just as we do, responds to questions and situations in all the same ways, but doesn’t have a mental life or ‘experience’ the world. It is also supported by the understanding of a mental being that does not have a physical form, such as a ghost or God. Physicality does not seem to necessitate mentality, and *vice versa*. Premise three is simply a description of the activities of reductionist science. It is common practice to describe the causal relationships of all the parts to describe and understand the properties of the whole. Lastly, premise four seems plausible because physicists can explain the activity of fundamental particles without referring to mental properties.

However, the problem arises because premises 2-4 entail the negation of premise 1. The set is inconsistent. The premises cannot all be true together. The chosen way to solve this problem (or rather, which premise is given up and why) will change how research involving the mind and brain is approached.

To reject premise 1 is to take an eliminativist position, akin to eliminative materialists. Eliminative materialists assert that while mental language or folk psychological explanations for human behaviours might be used, they are flawed ways of understanding the world as they theorize about the existence of an unobserved property. These states, eliminativists say, will not be explained by any state of a physical system because they are ‘wrong’ kinds of concepts to begin with.

Denying the second premise leads one to assert that the mental is reducible to the physical. That when we talk about someone being sad, or in pain, what we really mean is that their body is in a state that we label sadness or pain. This stance includes types of monism (that the mind and body are of the same material, be it metaphysically physical or not), identity theories (that there is a 1:1 mapping between states of the mind and states of the brain) and functionalism (which appreciates multiple realisability; i.e. that multiple physical states could map to one mental state).

Rejecting the third premise results in emergentism. This stance claims that while there is nothing more to the mental than the physical, mental properties arise out of complex integration of the constituent parts in ways that are unpredictable from the sum of the parts and their interactions. In other words, the mental is different from and comes from the constituent physical parts, but cannot be reduced to explanations at the physical level (material emergentism).

The final premise is the claim that the non-reducible components of the universe do not have mental properties. To negate this premise is to claim that the mental and the physical are neither the same, nor does one come from the other, but rather that mental properties are a fundamental property of the universe. One such position is panpsychism, which claims that everything is, at some level, conscious.

For our purposes, the primary division in the views individuals hold is the classical physicalism vs non-physicalism. Specifically, by this we mean to highlight those who think that looking at the state of the brain tells us something about the state of the mind (physicalism) from those who believe that the mind is fundamentally different than the brain and should be studied in other ways (non-physicalism). Whether an eliminative materialist, an identity theorist or a functionalist on one side and a dualist or emergentist on the other, differences in basic assumption shape how researchers approach educational neuroscience. Thus, delving into the ways in which researchers from different disciplines conceive of the relationship between the brain and the mind is an important task underpinning the transdisciplinary endeavour.

*The hard problem of consciousness*

The mind-body relationship is primarily a question of metaphysics; the way the world is. A tangential but related problem, termed “the hard problem” of consciousness was made popular by the philosopher David Chalmers in a paper called “Facing up to the problem of consciousness” [30]. The hard problem of consciousness is primarily a problem of epistemology; how we access knowledge about the world and the limits of this accessibility. The seminal question posed by Thomas Nagel motivating this question was “What is it like to be a bat?” [31], where he explained that the most important and interesting question of consciousness is the question of the *subjective character of experience*. The existence of the hard problem is sometimes used as an argument for the peculiar or special qualities of the mental, which would substantively differentiate it from the physical. The corollary of this question could be ‘what is it like to learn?’, which brings with it the same issues around subjective interpretation.

The hard problem of consciousness is the problem of qualia, of what it is like to experience the world; what it feels like to sense things and indeed to learn things. Consider different colours. When I look at a patch of red, I have a certain character of experience. Sure, I can differentiate red from green and blue, and even orange, but more than that, it looks a certain way. I can imagine an alternate scenario in which I call that same patch “red” but it looks to me as blue looks to me now. If all my colour percepts shuffled, I could imagine being able to describe the world with the same language, the same descriptions of similarity of colour, but with a vastly different subjective character of experience.

Chalmers says that the problem of explaining qualia, or the subjective character of experience, is the ‘hard problem’ of consciousness [30]. He contrasts this problem to the problems tackled by methods of the cognitive sciences. For example, how an object reflects light that is received by our retinas and then is interpreted by our brain to distinguish and identify that object is an “easy” problem. Why looking at a red object gives us the particular sensation of “redness” is the hard problem.

Trying to address the hard problem returns us to the same questions raised by the mind-body problem, but ultimately one’s stance on this problem is somewhat tangential to the mind-body problem. This is an epistemological problem about how (and whether) we can study all the relevant aspects of our consciousness, rather than about the way the mind and body are related. Chalmers suggests that there is an explanatory gap between the functional (easy) and the experiential (hard) that is a nontrivial further question [30]. It is hard to imagine what kind of purely physical explanation would bridge this gap.

Like in the mind-body problem, though not conclusively solved, there are a few ways people often react to this problem. There are those who think that the hard problem is not really a problem. Chalmers maps out these responses in a follow up paper [32]. The “type-A materialist” thinks that there is no hard problem; that there is nothing to explain over and above explaining the functions of the mind. Arguments for this include those by Daniel Dennett [33] and Patricia Churchland [34]. This position tends to line up well with eliminative materialist takes on the mind-body problem.

The “type-B” materialist claims that there is a hard problem (that qualia are more than just an illusory distraction from real problems), but that it can be explained without appealing to the non-material. One potential way of doing this is to appeal to identity theories, or the idea that there is a one-to-one, relationship between the mental and the physical [35, 36]. With regards to the mind body problem, this stance suggests that the presence of a physical system like the brain will necessarily generate consciousness and subjective experience. For every state of the brain, there is a corresponding mental state and *vice* versa. However, the same criticisms to this stance on the mind-body problem apply here also.

To round out the logical space of answering the hard problem, we turn to the non-reductive or “positive” responses. Philosophers who take this view conclude that the hard problem is real, and that it is reasonable to argue for a non-reductive stance on the mind-body problem. That is, those individuals who think that because it is not clear that we can objectively study all of the processes of the mind, there must be some aspect of it that is non-physical or, at minimum, not reducible to physical laws.

***The Hard Problem of Educational Neuroscience***

In discussing philosophical issues surrounding educational neuroscience, we will focus on the divide primarily between neuroscience and more basic sciences and the related humanities and social sciences, or “the big divide” [37]. As a caveat, the continuum of levels is not clearly delineated in reality, and many researchers will be, themselves, interdisciplinary by this framework. Nor will all members of a certain field have the same philosophical stances. However, by virtue of the way research is approached and undertaken, researchers make different assumptions about these issues [3, 4, 37, 38]. Additionally, many researchers have not had reason to stop and reflect on these particular questions, so may initially claim one view, but, upon deeper investigation, find they act with the assumptions of another.

These differences only become clear as researchers openly discuss philosophy amongst colleagues outside their own discipline. Within a discipline, research shares some common assumptions. For example, in the natural sciences, it is assumed that one will investigate a limited number of dependent variables, holding everything constant except the causal independent variable of interest. On the other hand, in ecological disciplines, the context and surrounding “confounding” variables are often seen as essential to the question or data of interest, and so are purposefully uncontrolled. When these researchers work together, the push and pull around design and what can be reasonably concluded from a particular set of evidence is called into question constantly.

Let us solidify these claims with some exploration of how the philosophical issues discussed earlier might affect researchers in educational neuroscience.

*Our two characters*

In this paper, we focus not on whether any particular viewpoint has more or less ground, but rather on the assertion that different disciplines have higher or lower concentrations of each of these viewpoints compatible with the assumptions made by the methods employed in each. Additionally, researchers themselves may not be able to defend their philosophical position as they are untrained in these arguments or have put little time into their point of view.

To avoid inviting philosophical arguments about these positions themselves, we will use two individuals to serve as exemplars for the ensuing discussion. The first is Dr Steepleton. Dr Steepleton is a neurobiologist studying memory formation in neural networks using fMRI and a paradigm that asks participants to discriminate between vowels and consonants (among other things). When considering the mind-body problem, Dr Steepleton is an eliminative materialist. She believes that the body/brain is the only source of information about our personal state, and that emotional words or descriptions of our internal life are meaningless relics of rhetoric devices for things we don’t yet fully understand. She also believes that the hard problem of consciousness is, as she puts it, ‘hornswoggle’; it is a meaningless problem and stems from our ignorance.

The second is Dr Lawagon. Dr Lawagon is an education researcher studying the way kindergarteners learn the alphabet in preparation for learning to read. She does interviews with parents, students and teachers, as well as video analysis of student engagement with letter activities in class. In terms of the mind-body problem, Dr Lawagon is a dualist who thinks that there are special qualities of the mind that make it unable to be reduced to purely physical interactions. Particularly, she thinks that the hard problem of consciousness is inaccessible to scientific inquiry and poses a particular conundrum for educators who wish to shape the subjective experiences of their students.

Let us presume that Dr Steepleton and Dr Lawagon attempt to undertake multidisciplinary research. It is conceivable (in fact, likely) that these two researchers will not discuss these issues of metaphysics as, at first, they assume that their colleague has a compatible philosophical stance (after all, researchers within their discipline often do) and, second, they do not think that abstract philosophical ideas could reasonably bear any weight on their research project. They are attempting to answer a research question “What is the best way to prepare children to learn to read?”, which has seemingly nothing to do with consciousness. So they continue with their joint project, unaware of how often this discrepancy in philosophical views causes conflict between them.

*The Hard Problem of Consciousness and the Mind-Body Problem*

Remember that the hard problem of consciousness is the question of qualia - of what it is like to experience the world – whilst the mind-body problem is about the relationship between body and mind. Let us consider how philosophical beliefs about the hard problem of consciousness might encourage our two exemplar researchers to perform research differently. Dr Steepleton doesn’t think the hard problem is meaningful. On the other hand, Dr Lawagon sees the hard problem as picking out a valuable part of the learning process that is inaccessible to scientific methods. This causes them to approach the question of learning to read in different ways.

Dr Steepleton comes from a philosophical stance under which changes and activations in the brain are the only true source of evidence about the learning process. Any behavioural changes, she thinks, are supervenient on and ultimately reducible to the neural changes. Studying the brain, in principle (though maybe not in practice) should leave no desired piece of the puzzle out. Therefore, Dr Steepleton studies patterns of brain activation to answer her questions of learning. On the other hand, Dr Lawagon thinks that there are special mental qualities that do not reduce to the physical brains of the students she studies. She uses qualitative methods including subjective report, because she thinks that this gives her a more complete picture of the learning process.

It is clear that the philosophical viewpoints of Dr Steepleton and Dr Lawagon are logically incompatible. However, even more significantly, and more often than not in collaborations like this, these philosophical assumptions are a backdrop to the research, which the individuals see as unquestioned (because working within their own field usually involves others with either compatible or equivalent theories) and irrelevant. While underlying each of the disciplinary ontologies, they are not explicitly part of the collaboration or negotiations. When it comes to the point of deciding the relevant or important pieces of information to collect from participants and interpreting the relationship between these measurements, as well as how to understand the results in relation to the overarching research question, it is likely that these researchers will disagree; and not for the reasons they think they are disagreeing.

Assimilating language used across disciplines is often seen as a major hurdle to interdisciplinary collaborations [39]. Using an ambiguous word that has lay meanings as well as implied philosophical meanings and scientific operational definitions can cause confusions that are not always immediately apparent. The use of words like thinking, learning or consciousness [40] can easily fall into this trap in educational neuroscience research.

Since these philosophical assumptions and use of language are often intimately tied to researchers’ methods and explanations, overcoming this obstacle may initially feel threatening. Researchers may initially react negatively to challenging their disciplinary assumptions and ontologies. To effectively work together, researchers need to face these challenges and directly communicate these assumptions. Through this process of discussion with colleagues, researchers will need to find ground on which they can build answers together, with each feeling firm philosophical footing. Sometimes, this will prove too hopeful.

While the aim of these discussions is not to change anyone’s mind, since many non-philosophers have not discussed these issues in detail before, researchers may find that they do not have reason to stand by their initial assumptions. Or they may feel more strongly in their convictions by the end. Navigating the philosophical underpinnings of their research will nonetheless make clear where collaboration should start so that each involved researcher feels assured in the chosen question and evidence the team will use to answer that question.

*Is there room for zombies in the classroom? Philosophical views constrain possibilities for knowledge in the Science of Learning*

The prospects for the field of Science of Learning are constrained by one’s philosophical stance on the accessibility of knowledge in this area. If we take the view that the hard problem of consciousness is a real problem, we see how it constrains the possible influence of neuroscience on teaching practice. All measures of the brain – from individual neuronal electrical spikes to global blood oxygen level shifts - and all measures of the subjective experience – from surveys to self-reports - are indirect windows to the mind. Assumptions are made on the basis of prior data and neural correlates, but there is no direct empirical evidence for the relationship between mind and brain, and there may never be this kind of evidence. The only source of understanding about this is through philosophy (empirical arguments contribute to an *a forteriori* conclusion). Once some basic assumptions about these contested relationships are established and made explicit, researchers can move forward in how they collectively think it best to answer (or not answer) the relevant questions empirically.

Consider how the philosophical perspectives we address here constrain the prospects of the connectome project and artificial intelligence ([www.humanconnectomeproject.org](http://www.humanconnectomeproject.org)). The “human connectome project” is an effort to map the structural (which cells connect to which cells) and functional (which areas of the brain interact/are simultaneously active when performing a specific cognitive task) connections in the human brain. The project is funded by a thirty million dollar grant by the NIH starting in 2010; a massive sum for a project with far reaching goals. Presumably, knowing every single connection between cells in the brain and how they interact to allow for cognition will help us make vast strides in the field of neuroscience and brain disorders [41].

Importantly, given data from the human connectome project, it should be possible to build a digital replica of the human brain. Using this, it will be possible to run simulations of various brain states and even provide the simulation with a proxy behavioural output, or build it into a sophisticated robot and watch as the robot interacts with the world. Now, depending on philosophical point of view, manipulations this robot could also provide meaningful insights into who we are [42]. Granted, this robot’s neural architecture would be simpler than the human brain – for example, it would lack the diversity of biochemical subtypes, neuronal morphologies, glial cell and neural vasculature functions [41]. Nevertheless, such an endeavour could provide fundamental understandings of what it means to be human.

However, assuming it is similar enough in the important ways, would the robot with the connectome brain give us an ethical playing field for educational experimentation? The answer to this question depends on the philosophical assumptions one brings to the question. From a functionalist perspective, such a robot could be considered conscious. If the connectome robot is conscious in the right ways, is it ethical to experiment on it? Questions about the scope of this research direction become primarily ethical questions. From a dualist perspective, replicating the neural architecture would not entail an equivalent replication of the mind, and so such a project may not seem fruitful in the right ways. An eliminative materialist, who thinks that the whole body has to function together to give the right kinds of inputs and outputs, might argue that without all of the relevant bits, the machine would not teach us about the right things. Essentially, a researcher’s opinion on the scope of such a research endeavour is dependent on their philosophical assumptions about the underlying phenomena. Some of which would not clearly be empirically answerable. Assuming a connectome robot could pass a Turing test, how would it be possible to empirically prove the existence or contents of its conscious experience?

Perhaps understanding the differences between disciplinary assumptions regarding the mind body problem and the hard problem of consciousness gives an insight into why scholars disagree on the possible impact of neuroscience on education. Rather than *how* does the research community successfully translate knowledge, the pertinent question becomes *can* such a community translate knowledge. The answer? That depends on the philosophical views of the members of the community. Again, although it is not our aim to offer concrete suggestions, it is important to note that some individuals may adhere to philosophies that all but eliminate any chance for translation whilst others may be flexible enough in their boundaries to allow for partial or full translation between different fields. Whether or not there is a minimum threshold required for successful interdisciplinary work will only be established by explicit discussion of these issues by participating researchers early in the translation process.

***The Hard Problem of Translation***

*How solving this problem becomes a problem of communication between disciplines and translation to applicable knowledge*

Fundamentally, other issues in philosophy of science are bound to constrain conversations about translation and the applicability of scientific explanations. Questions about what counts as evidence, how we can ‘prove’ something (if at all), or what counts as an explanation are all, whether consciously or not, directly influence researcher’s questions and methodologies. Of particular relevance here is the unity of science and reduction in the special sciences (i.e. sciences that are not physics). Philosophers who accept reductivism, the claim that scientific endeavours are importantly unified in that the laws of sciences other than physics can ultimately be reduced to laws of physics, will differ in their understanding of the purpose of the special sciences to those who are non-reductivist. While this kind of claim usually arises out of a stronger belief in substance monism, that there is only one kind of substance (usually considered physical), it is not necessary to endorse reductivism based purely on a commitment to physicalism, as Fodor [43] explains.

In educational neuroscience research, this question could be reposed as whether it is feasible to “translate” the laws of education to laws of behavioural psychology, and those again to laws of cognitive neuroscience, and those again into cellular neuroscience and again to biochemistry, chemistry and ultimately down to physics. In other words, is it even possible to translate across and beyond the seven orders of magnitude described by Anderson [17]? Other than cognitive efficiency and cognitive economy for researchers, is there something that the higher “levels” give us that cannot be reduced to the “more basic” disciplines? Assuming a complete set of laws in each discipline (in practical terms, no such laws exist yet), should reduction be attempted, or are the solutions to learning available in the knowledge of each discipline as it stands alone?

Relevant to this question is the importance of neuroscience to questions of psychology. The *neural doctrine* claims that any scientific understanding of the mental will come from neuroscience [44]. This claim heavily influences the direction and scope seen in educational neuroscience. Ultimately, it asks whether mental sciences other than neuroscience are merely placeholders for future neuroscientific theory.

Meaningful prescriptive translation, that is, successfully informing teachers on what practices they should be exercising in the classroom is unlikely to come from neuroscience straight to education. Rather, success in the science of learning is likely to come from conceptual, functional, or diagnostic translation; that is, descriptive accounts and/or direct manipulation of relevant cognitive and cellular processes to learning [14, 18]. These descriptive and intercessory processes may inspire, constrain, or describe educational practices, but will unlikely be able to prescribe a recipe for the best way to teach.

*Is Educational Neuroscience special?*

While we have focused on a particular set of philosophical stances on problems specific to the educational neuroscience collaborative mission, these issues are not unique to this area. Many global and social problems span the disciplinary boundaries and require varied methods to address. Of special relevance are those which require communication across the “big divide” [37], as these struggle with more disparate methods driven by more varied philosophical foundations.

*Prima facie,* medical translation might seem like a good framework for successful translation of the kind we have been describing. It seems apparent that medical translation involves synthesis of information across broadly distinct research areas, albeit with an ultimate focus on biology and related methodologies. However, we argue that other problems, which involve disciplines other than the hard sciences, and tackle problems which are more obviously value-driven or socially and politically fraught, are where the philosophical assumptions are most clearly at work in causing conflict.

This is primarily because the researchers’ motivations and questions of interest are, from the outset, very different. Consider the contrast between translation in *medicine* and translation in *health*. Medicine is clearly focused on mechanisms in the body (even considerations of things outside are concerned with how they impact the bodily functions). Additionally, its goal is cohesive (to save lives and eliminate illness); its outcomes are easily measured (how many lives saved by a certain practice or treatment). So despite involving research being carried out at multiple levels, and the sometimes difficult task of finding the appropriate bridge laws between these explanatory levels, this kind of collaboration is vastly easier than that of *health*.

The multidisciplinary problem of healthencompasses all of medicine with the addition of value-laden questions about quality of living (including dignity, autonomy, mental health), patient care, attitudes towards disability, an individual’s participation in society, political issues of payment for treatment etc. It is the broader question of how do we stay *healthy* and encourage *health* in society. Researchers likely come to these questions with many different motivations, and from all disciplinary backgrounds. Social scientists, biologists, doctors, philosophers, politicians, and economists will all be involved, and will bring with them the philosophical baggage of their discipline. Communication and translation across these disciplines will be much more difficult than in *medicine.*

Like health [45-47], there are many other areas of broad interdisciplinary collaboration that involve such disparate research ontologies. These include questions of ecology and conservation [3, 48], geography [49], international affairs [50, 51], agriculture and biotechnology [52] and, of course, the science of learning [5, 11]. There would be equally fraught philosophical assumptions embedded in the practices of each of these interdisciplinary projects.

*How can we address this?*

Once again, the aim of this piece is not to solve philosophical disputes – it is merely to highlight the important and often overlooked role they may play in interdisciplinary work. With that said, there are a couple tools researchers can utilize to facilitate discussions surrounding these issues early in the translation process. Eigenbrode et al. [4] give a framework for workshops around philosophical assumptions in interdisciplinary teams. Questions include those of motivation and the role of basic research, describing and evaluating the traditional scientific method, defining *evidence*, the existence and role of truth in research, the value placed on replication, defining *knowledge*, the value and possibility for objectivity, the unity of science and the relationship between phenomena in the various disciplines [4].

In addition, Donoghue & Horvath [53] offer a concrete framework through which interdisciplinary teams can locate and understand each other’s work. Based on an abstracted-systems model, this framework does not solve issues of philosophical disagreement – rather, it makes it easy to frame research from differing fields within specific levels so as to clarify what assumptions varying researchers are likely to utilize to drive their research, data, and explanations. In addition, this framework suggests that effective prescriptive translation need only traverse adjacent levels of organization. This eases the burden placed on individuals from highly disparate fields (e.g. – cellular neuroscience and education) and requires conversations and accommodations be made only at the interfaces between adjacent fields (e.g. – cellular neuroscience and systems neuroscience).

Other than encouraging discussion of this type, we provide no other solutions to the mismatched philosophical assumptions, as this will rely on the dynamics and values of the specific interdisciplinary team. It is important that these discussions come in the preparatory phases of the research collaboration, as these issues may only become apparent in the interpretation of results, which may have been resolved earlier with a stronger design, which more fully addresses the questions of interest for all parties. Though these conversations may be difficult, they do not negate any possibility of successful interdisciplinary collaboration. Any issues of philosophical disagreement can ultimately have an effective arbitrator in the elucidation of and reference to concrete outcomes and goals established early in the project development phase. By deferring to these established goals, disagreements can be seen as guides as to how to proceed in order to achieve common outcomes instead of possible de-railers of the overall process.

*Conclusions*

Given that there are many valuable ways of knowing and different disciplines are at least currently epistemologically irreducible, in cases where different disciplines study the same subject matter, disparate disciplines have good reasons to work together. However, it is an empirical truth that different disciplines make different assumptions about metaphysics and epistemology around these subject matters, which likely leads to their different preferred methodologies and definitions of evidence. Since many researchers do not see these philosophical issues as central to the interdisciplinary subject matter at hand, they fail to talk about these important issues. This causes conflicts that are seemingly about interpretive language, methods or results, but actually stem from these deeper philosophical assumptions. The solution is to communicate directly and transparently about these issues at the outset and iteratively in the process of interdisciplinary collaboration. Along with others, we argue for confronting disciplinary assumptions in order to foster truly integrated interdisciplinary projects [3, 4, 38]. To resolve the conflicts and develop a more inclusive and productive form of collaboration, researchers should exercise philosophical dialogue with their interdisciplinary peers.

Conflicts of interest: none

Funding: Australian Research Council Grant: ARC-SRI: Science of Learning Research Centre (project number SR120300015).

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