# Research Paper: What is the Science of Learning?

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## Introduction

Learning is a complex process. Until around three decades ago, teaching and learning practices were largely informed by theory developed by educational psychologists who investigated the relationship between pedagogy and learning outcomes by analysing observable behaviour (Chang et al., 2021; Kim and Sankey, 2022). However, since the late 20$^{th}$ Century, advancement in innovation and technology has enabled the exploration of cognitive brain function through neuroimaging techniques to study the neural correlates of behavioural and cognitive processes across a range of disciplines, including the social sciences, resulting in what is now referred to as the Golden Age of Neuroscience (Feiler and Stabio, 2018; Thomas et al., 2019; de Bruin et al., 2018). The implications of human brain research for education were quickly identified as an opportunity to improve teaching practices, student learning and outcomes, directly and indirectly (Ansari et al., 2011; Thomas et al., 2019). This led to the emergence of a new field of research, educational neuroscience, or, the Science of Learning, challenging many of the theories which had previously been influential in education (Kim and Sankey, 2022). The Science of Learning encompasses three research fields; cognitive neuroscience, education and psychology. It provides opportunities not previously possible to analyse changes in the brain related to education and teaching practices and explain how students learn so that these findings can be applied in the classroom to optimise learning outcomes. However, despite the promise and hope that educational neuroscience initially offered, translation from research to education policy and practices is proving to be difficult and contentious (Thomas et al., 2019; Almarode and Daniel, 2018; Feiler and Stabio, 2018), however, progress is being made.

## The Science of Learning: it's new and it is about more than just the brain

Essentially, the Science of Learning is knowledge, derived from scientific data, about how people learn, what affects their learning and how to enhance the learning process through developing, delivering and evaluating effective teaching instruction (Hays, 2006). While child learning and development occurs in a complex but interconnected system as per Broffenbrenner's bio-ecological systems theory of human development (Rosa and Tudge, 2013; Kim and Sankey, 2022), the aim of the Science of Learning is to improve educational outcomes, largely by changing the most proximal factors to learning outcomes: ability, motivation and attention, health and nutrition (Thomas et al., 2019).

While previous theories of learning and development have focussed on the socio-cultural context of learning stages and phases to inform education policies and practices, the Science of Learning shows that the new field of educational neuroscience provides the opportunity to close the gap in learning experiences and educational outcomes for all learners. Neuroscience can now provide insight into previously unobservable processes within the brain which underlie attention, perception, memory and learning as well as behaviour, previously inferred by educational psychologists (Kim & Sanky, 2022).That is, neuroscience provides the opportunity to fill the missing piece of the puzzle in understanding the process of learning and how to improve educational outcomes. Until a few decades ago, teaching instruction was informed by a 'theory into practice' methodology, rather than developing theory from practice (Kim and Sankey, 2022). Neuroscience offers a shift to an interplay between research and practice to improve pedagogical theory, firmly connecting the study of education to educational practice. By providing an insight into unobservable processes within the brain which underly attention, perception, memory and learning as well as behaviour in response to stimulus in an educational setting, neuroscience can help identify, and inform, the most effective teaching practices. Educational neuroscience research has shown that learners dynamically and actively construct their own brain's networks as they navigate through social, cognitive, and physical contexts; the brain both shapes and is shaped by experience, including opportunities individuals have for cognitive development and social interaction (National Academies of Sciences Engineering and Medicine, 2018).

Within the research community, educational neuroscience is considered an interdisciplinary collaboration between cognitive science, education and psychology whereby the whole is greater than the sum of the parts (Feiler and Stabio, 2018). The Science of Learning, as it is referred to in the wider education ecosystem, is a relatively new field of research which aims to translate research findings on neural mechanisms of learning to educational practice and policy as well as the identify the effect of education on the brain, mind and behaviour (Thomas et al., 2019; Feiler and Stabio, 2018). The new field of neuroscience provides a more granular insight into the learning process which is challenging long held beliefs and understandings about education and human development (Kim and Sankey, 2022).

Given that cognitive neuroscience provides an understanding of brain function to observations of behaviours involving learning (Howard-Jones, 2008), educational neuroscience can assist inform new teaching methods, and evaluate them, based on their effectiveness in both educational and social/behavioural contexts (Feiler & Stabio, 2018).

**The Science of Learning: the challenges and the opportunities**

The Science of Learning offers reciprocal interactions in learning between the three fields of research – education, psychology and neuroscience - and how they must all work together to facilitate effective learning and successful educational outcomes.

Despite the hope promised, there remains scepticism regarding the potential of the Science of Learning to improve student outcomes. This is explained in the literature as an outcome of divergent philosophies of learning (Howard-Jones, 2008; Thomas et al., 2019) and a reluctance to support inter-disciplinary research, characterised by competition rather than collaboration between the fields of research (Thomas et al., 2019). This is evident in numerous journal articles in which academics in one field respond to comments from academics in another field (see for example Bowers, 2016b; Bowers, 2016a; Gabrieli, 2016; Howard-Jones et al., 2016).

Deep philosophical differences regarding the factors which underpin the process of learning and human development exist (Ansari et al., 2011; Howard-Jones, 2008). Traditional educational theory supposes that learning is socially constructed. Constructivist theories of learning, stage- and age-based, informed by the work of Piaget and Vygotsky, believe that learners sub-consciously construct knowledge based on their own experiences, interactions and prior beliefs (Illeris, 2018; Kim and Sankey, 2022) rather than through the interaction of neurobiological systems with teaching practices, the premise of educational neuroscience. This philosophical difference suggests that educational neuroscience is simplified given that education is a social phenomenon and social problems require social solutions, not reduction to neural mechanisms (Thomas et al., 2019). For this reason, it is argued that the importance of social and cultural factors in learning that should not be excluded from the educational neuroscience research parameters (Howard-Jones, 2008; Illeris, 2018).

Educational psychologists claim that their field provides sufficient knowledge of the scientific understanding of learning processes to inform education practices and that neuroscience is a 'bridge too far' (Bruer, 1997). However, as Thomas et al. (2019) observe educational psychologists have a 125-year history studying of learning, and still struggle to properly inform teaching practices to optimise the learning outcomes for all students. The research method applied by educational psychologists exclusively focuses on what is directly observable; behavioural responses to stimuli, and does not capture the unobservable processes between the stimulus and the response. As a result, educational psychologists infer causal relationships to explain and/or predict behaviour which can lead to erroneous theories (Thomas et al., 2019). Neuroscience now provides an insight into those unobservable processes within the brain which underlie attention, perception, memory and learning as well as behaviour (Kim and Sankey, 2022). Failure of educational psychologists to acknowledge that development of the brain and mind is a mutually dependent, experience-dependent process limits the impact their field can contribute to improving educational outcomes. Experiences such as interactions, relationships and schooling shape not only what information enters the brain but also the brain's ability to process that information. These experiences build strong brain architecture and are necessary for developing the affective, cognitive, social, emotional, and behavioural competencies foundational to development and learning over the lifespan (Cantor et al., 2019). Cognitive neuroscientists believe that mind and brain must be explained together and argue that advances in educational psychology theory, and thus more effective pedagogy, will occur more quickly with closer ties to neuroscience (Thomas et al., 2019; Howard-Jones, 2008). Given that neuroscience is the study of brain mechanisms underlying behaviour, the study of cognition should be considered a vital bridge in linking the understanding of brain function to observations of behaviours involving learning (Howard-Jones, 2008). As such, educational neuroscience can assist inform new methods, and evaluate them, based on their effectiveness in behavioural contexts (Feiler and Stabio, 2018).

While cognitive neuroscientists acknowledge that no classroom ready knowledge from neuroscience is ever likely to exist (Thomas et al., 2019), teaching in the classroom is an interactive process delivered at a point in time, so it also cannot be directly driven by theory (Feiler and Stabio, 2018). However, understanding how the brain learns gives the classroom teacher a greater probability that any educational neuroscience-informed teaching instruction adaptations will not simply be trial and error (Almarode and Daniel, 2018). Even so, the methods required to collect neuroscience data, such as brain imaging, require controlled experimental situations not usually conducive to a classroom setting and could raise questions of validity. However, as technology continues to advance at a rapid pace, more classroom friendly, school-based research methods are becoming available, for example, the electroencephalogram (EEG) (Kim and Sankey, 2022). To overcome these perceived limitations, neuroscientists should work collaboratively with teachers to develop research questions that are relevant to education and can also be addressed by neuroscientists (Almarode and Daniel, 2018).

Another major challenge for the Science of Learning is the seductive allure of neuroscience and presence of 'neuromyths' (Thomas et al., 2019). While there is a legitimate desire of policymakers to use scientific evidence to inform education policies and practices, educational neuroscience is in its infancy and there is risk of premature translation to pedagogical practices due to the complexity of brain function research (Almarode and Daniel, 2018; Thomas et al., 2019). This could lead to false perceptions regarding the capabilities of neuroscience research among educators and the wider community (Feiler and Stabio, 2018). Neuromyths are misconceptions, mistaken beliefs, misunderstandings or misinformation about the brain, education and human development among teachers and/or the public that are either not yet supported by the data or actively contradicted by existing science such as AKV learning styles, hemispheric learning and fatty acid supplements (Sullivan et al., 2021; Kim and Sankey, 2022; Kim and Sankey, 2018). The pervasive nature of these neuromyths on education policy, curriculum design and pedagogy could lead to the misdirection of valuable resources and mislabel children and therefore pose a risk to student outcomes (Kim and Sankey, 2018; Sullivan et al., 2021).

Education policy and practices appear highly susceptible to fads (Jansen et al., 2022; Brown et al., 2014; Pekrun, 2019; Sweller, 2022). Identified current fads include, but are not limited to, well-being, creativity, 21st century skills, curiosity, motivation and emotions. While each of these concepts are important issues in education, they should not be considered in isolation of other factors which contribute to learning outcomes (Jansen et al., 2022). The greatest risk in the mobilisation of Science of Learning knowledge and it's practical application is not harnessing the reciprocal interactions in learning between the three fields of research; the whole is greater than the sum of the parts (Feiler and Stabio, 2018).

The lack of understanding of Science of Learning approaches is evident in relatively recent, and ongoing, calls for Australian education to reform for the 21st Century in response to the creation of a knowledge economy, and the need to develop higher-order skills and competencies such as the 4C's – communication, collaboration, critical thinking and creativity (Centre for Education Statistics and Evaluation, 2019). This is demonstrated in the Australian Professional Standards for Teachers which requires teachers at all levels to demonstrate the use of teaching strategies to develop student's "knowledge, skills, problem-solving and critical and creative thinking". The 21st Century approach to education and the development of competencies and skills demands that the curriculum focus on the application of knowledge without prioritising the acquisition of foundational knowledge first (Crato, 2021). Without knowledge there is no foundation for the higher- level skills of analysis, synthesis, and creative problem solving (Brown et al., 2014).

While Brown et al. (2014) say 'accumulating knowledge can feel like a grind, while creativity sounds like a lot more fun', cognitive science provides the evidence that knowledge held in long-term memory is the first prerequisite of critical and creative thinking (Sweller, 2022) and that all new learning requires a foundation of prior knowledge (Brown et al., 2014). As the psychologist Robert Sternberg and two colleagues put it, "one cannot apply what one knows in a practical manner if one does not know anything to apply."(cited in Brown et al., 2014: 18). Evidence also shows that differences in students' creativity and critical thinking is not due to differences in thinking strategies, but rather on differences in students' knowledge (Sweller, 2022).

At the same time, curiosity and interest are central to the generation of knowledge (Pekrun, 2019). As a psychological state, curiosity includes three components: recognition of an information/knowledge gap, anticipation that it may be possible to close it, and an intrinsically motivated desire to do so (Pekrun, 2019).

As such, student motivation is also key to academic success. However, from a Science of Learning perspective it is essential to better understand which variables influence motivation. A systematic review of meta-analyses undertaken by Jansen and colleagues in 2022 (Jansen et al., 2022) found that certain student variables, especially their own prior achievement and perception of their own competence are key for students' motivation. They also found that teacher variables were critical as well, notably the quality of their instruction and having positive relationships with their students in school (Jansen et al., 2022).

A key finding from the Jansen and colleagues study was the importance of fostering academic skills, positive self-beliefs, and relationships in parallel, not in isolation. If students see that they are making progress, feel welcome in their schools and classrooms, and are connected to their teachers and peers, they are more likely to be knowledgeable, motivated, engaged, curious, creative and successful in their learning.

Regardless of the philosophical differences there is a great need to improve educational outcomes, and therefore there exists a great need to acknowledge the common goal of the three disciplines and align the increasingly vast, field-specific bodies of knowledge currently under-utilised to the detriment of learners, education systems and communities (Cantor et al., 2019).

**Conclusion**

The Science of Learning offers much potential to improving educational outcomes. The integration of education, psychology, and neuroscience into an interdisciplinary field based on research to practice and vice versa, which prioritises helping students learn and teachers teach effectively, should be embraced by education policy makers and practitioners. The reality is, new and continually evolving discoveries of brain function and development combined with the effect of education and other contexts underlying engagement and learning has the capability to inform innovation in education to improve teaching practices (Feiler and Stabio, 2018).  While there are challenges in transitioning to new ways of thinking due to the relative infancy of the field, the competitive nature of academia inhibiting collaboration and the requirement for a philosophical, and paradigm, shift, as well as the risks of premature application, acquiring and applying new knowledge is the purpose of education. The Science of Learning provides the best understanding of what, why and how to achieve it most efficiently and effectively.

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