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At the heart of learning: navigating towards educational neuroscience in health professions education

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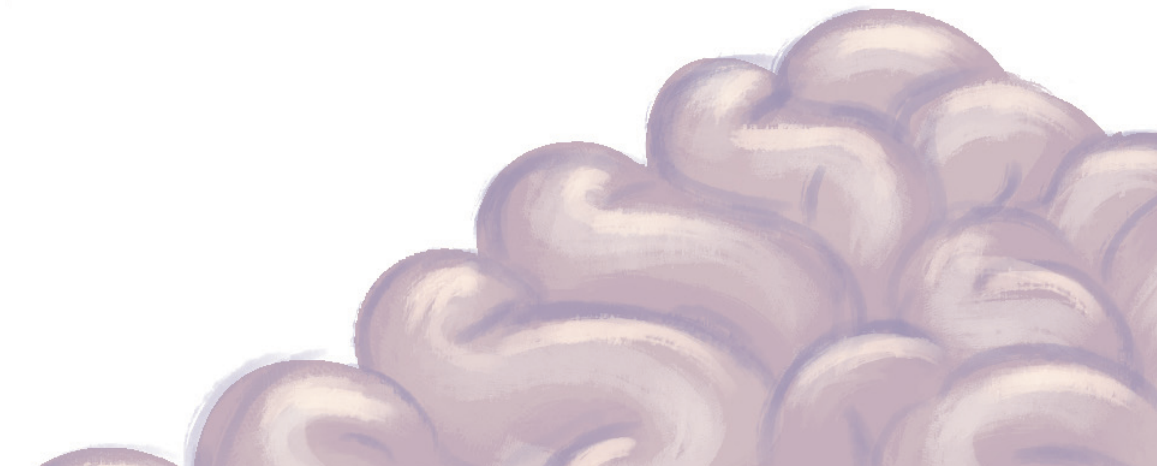
Chapter 1

General introduction



· Scope ·

Learning influences the brain. Every time you learn a new fact, a new concept or a new skill your brain has changed. The brain also influences learning. Your ability to learn is constrained by the architecture and functioning of the brain. Despite the close relationship between the brain and learning, neuroscience has remained remarkably distant from the classroom. In my quest to improve health professions education, this gap highlights an opportunity. Building a bridge between neuroscience and education may pave the way for evidence-informed education in the health professions.

In this thesis, I use *educational neuroscience* as a source of inspiration for developing evidence-informed health professions education. The overall aim of this thesis is to improve health professions education by investigating learning processes using an educational neuroscience-inspired approach.

This introductory chapter describes the rationale behind our studies. I describe the scientific field of educational neuroscience as well as its relevance to health professions education. Subsequently, I elaborate on three specific learning processes; spaced learning, concept learning, and metacognitive learning, as these are the focus of our research. This chapter concludes with an overview of the studies included in this thesis.

· The science of learning and why it matters ·

"When the why is clear, the how is easy." – J. Rohn

For decades, there has been a drive towards evidence-informed health professions education. Evidence-informed implies that education should be integrated with evidence from research to find best practices and improve the quality of education and healthcare accordingly (Nelson & Campbell, 2017; Sharples, 2013). Educators and policymakers are increasingly called upon to apply evidence-informed education in their curricula in order to facilitate meaningful and effective education (Thomas et al., 2019a; Durning et al., 2012; Van Der Vleuten, 2000).

The pursuit of educational excellence should be reflected by curricula with a scientifically sound basis (Ramani, 2006). Research informing our curricula should partly be directed at advancing our understanding of students' learning processes (Ruiter et al., 2012). For example, what they learn and how they learn. Research on learning processes can be informed by the tremendous growth in knowledge about the human brain over the last thirty years (Ansari et al., 2011). And so, I arrive at the interdisciplinary research field named educational neuroscience, which connects neuroscience, through cognitive psychology, with education sciences.

Why educational neuroscience? To become more evidence-informed, health professions education should start looking beyond boundaries. The evidence on the science of learning in fields such as neurobiology, cognitive psychology and higher education is there for the taking. My goal is to blur the boundaries between these fields using educational neuroscience-inspired research, in order to achieve: more evidence-informed education, more effective education, better learners, better healthcare professionals, and ultimately, better healthcare.

· Educational neuroscience ·

"Integrated research of two domains should be driven by an urge to understand." – A. Einstein

There is a growing belief among scientists, teachers, and policymakers that education benefits from an understanding of the brain (Jones, 2009). Early enthusiasts included educational psychologists such as Edward Lee Thorndike. In his PhD thesis written in 1926, dr. Thorndike already claimed that learning has its physiological basis in the structure and activities of neurons and accessory organs which compose the nervous system (Thorndike, 1926). The field of educational neuroscience established itself several decades later, in the early 90s.

Educational neuroscience is an interdisciplinary scientific field which combines research from cognitive neuroscience, cognitive psychology, and other related disciplines to explore the interactive processes between biology and education (Goswami, 2006). The collective belief is that these disciplines should act in synergy in order to understand the learning brain and improve education (Sigman et al., 2014). As written in a recent commentary by Howard-Jones et al. (2016):

"The relationship between neuroscience and educational practice can be likened to the relationship between molecular biology and drug discovery, including the arduous process of clinical trials. The basic science tells you where to look, but does not prescribe what to do when you get there. Similarly, neuroscience may tell you where to look – that is, what neural functions are typical or impaired and how these operate – but this knowledge must be transformed by pedagogical principles and then assessed by behavioural trials in educational contexts, the equivalent of clinical drug trials."

It is important to emphasise that our research does not aim to improve education through neuroscience directly. As illustrated by the quote, educational neuroscience utilises neuroscience as a supplementary ground which can anchor and enrich educational practice. If a psychological construct has a biological substrate, it will be better understood if the underlying mechanisms are

supported by both behavioural and biological data. In turn, a better understanding of behavioural and biological processes leads to better guidance for educational interventions (Ansari et al., 2011; Howard-Jones et al., 2016). Vice versa, educational practice may serve as a source of inspiration for neuroscientists, by providing novel research conditions through unique real-world settings (Goswami, 2006; Sigman et al., 2014). Our research is inspired by the systematic interactions between neuroscience, psychology, and education on the fundamental and practical level. These interactions may lead to a common language with common questions to advance theory and practice in health professions education (Thomas et al., 2019b).

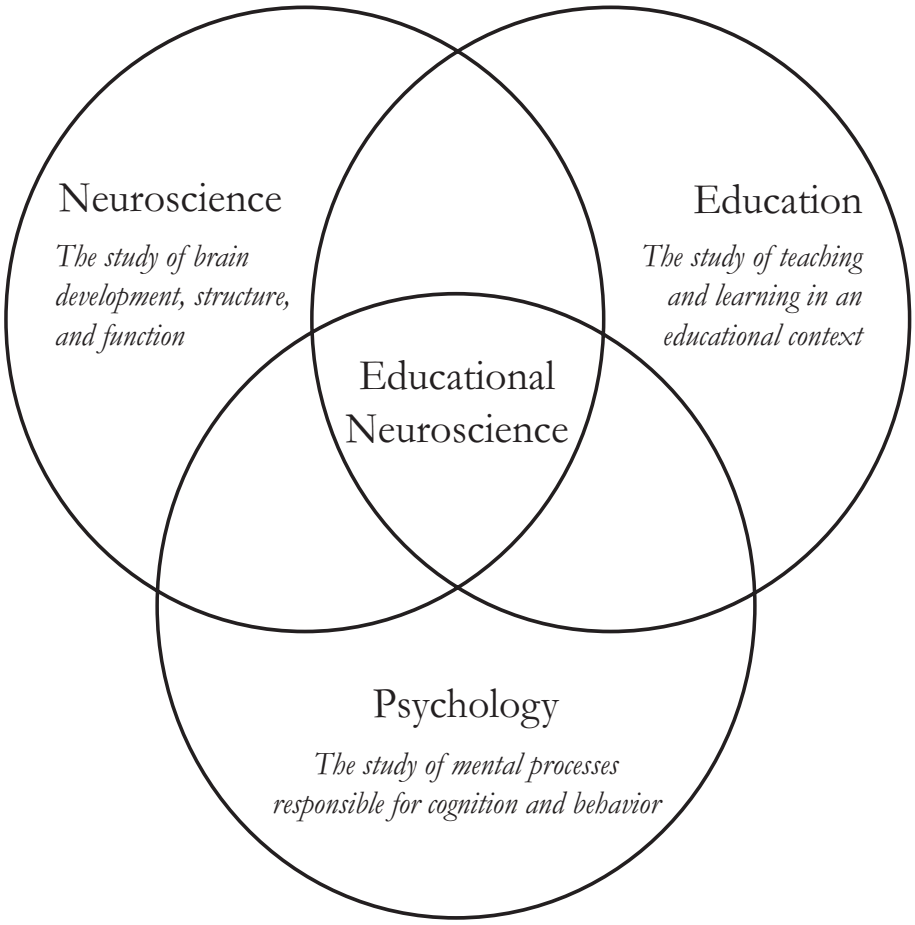


Figure 1 | The systemic interactions between neuroscience, education and psychology. Adapted from Sousa, 2010.

· Focusing the research topic ·

"The sun's rays do not burn until brought to a focus." – A. Bell

The current role of educational neuroscience in health professions education research is limited (de Bruin, 2016; Friedlander et al., 2011; Ruiter et al., 2012). Nevertheless, various scientists have claimed that neuroscientific theories may have great impact on health professions education (Patel et al., 2009; Regehr & Norman, 1996). This includes translating insights from neuroscience to education on the one hand, and informing the science of learning through educational best-practices on the other hand. This line of reasoning has led to the creation of this thesis.

In this thesis, we focus on studying learning processes. But, how do we decide which specific learning processes should be studied? Considerable opportunities for health professions education have already been discussed in the literature. We selected three highly interesting research topics from the viewpoint of health professions education, which are also actively studied in neuroscientific and psychological disciplines: 1) spaced learning, 2) concept learning, and 3) metacognitive learning (de Jong et al., 2009; Friedlander et al., 2011; Ruiter et al., 2012). Together, these learning processes are fundamental to the three types of knowledge described by Bloom's revised taxonomy for establishing educational goals (Herwaarden et al., 2009; Krathwohl, 2002). First, spaced learning is a process by which learning is distributed over time in order to enhance retention. From Bloom's perspective, spaced learning facilitates acquirement of factual knowledge, which is necessary for health professionals to establish a solid knowledge base. Second, concept learning is a process related to the understanding of scientific concepts. From Bloom's perspective, concept learning facilitates conceptual knowledge, which is essential to health professionals in understanding the mechanisms of human body function. Third, metacognitive learning is a process that focuses on reflexivity; "thinking about one's thinking". From Bloom's perspective, metacognitive learning facilitates metacognitive knowledge, which is of critical importance for achieving the desired lifelong learning attitude in our health professionals. Below, I provide an outline of each learning process and its relevance to health professions education.

· Spaced learning ·

"There is no learning without remembering." - Socrates

Students have a hard time recalling the learning material taught in medical school. Recent studies have demonstrated that half of the first-year medical knowledge

could not be reproduced by second-year medical students who were retested unprepared (Schneid et al., 2019; Weggemans et al., 2017). Medical educators and students should be aware of this, since long-term retention of knowledge is of great importance for accurate clinical reasoning and adequate clinical practice. Consequently, there is a need for methods that improve knowledge retention.

Spaced learning is a method that could help to amend the difficulty of knowledge retention. If learning is distributed over multiple sessions and repeated over time this leads to better and longer retention (Carpenter et al., 2012). In health professions education, innovative forms of spaced learning are finding their way to the classroom. However, an overview of these applications is lacking due to the great diversity in the terms and definitions used in the literature to refer to spaced learning. Moreover, in the light of educational neuroscience we are interested if such research is informed by psychological or neuroscientific theories. For example, neuroscientists have recently advocated the use of short timescales in spaced learning (Smolen et al., 2016). Their research shows that biochemical cascades involved in memory formation act on different temporal domains with timescales from seconds to hours to days. The dynamics of molecules working on these timescales, such as second mes□sengers and kinases, may contribute to the spacing effect. It would be of interest to investigate if short spaces could be of use in those settings that are currently overlooked, such as traditional lectures.

Spaced learning is the subject of study in Chapter 2 and Chapter 3 of this thesis. These chapters provide an overview of spaced learning studies in health professions education research and the use of psychological and neuroscientific theories. Additionally, the potential of using short spaces in a spaced lecture format is explored.

· Concept learning ·

"The more you know, the more you can know." - Aristotle

Students find it challenging to obtain an accurate conceptual understanding of human physiology (Michael, 2007). Their level of conceptual understanding has shown to be rather limited and difficult to enhance through traditional teaching methods (Palizvan et al., 2013). One of the primary reasons may be that students suffer from misconceptions, which impact on their learning process. Misconceptions can be defined as ideas that are incorrect according to current scientific views, resulting in misunderstanding of new information (Wandersee et al., 1994). Misconceptions appear very resistant to change, since they continue to exist even after taking the corresponding courses at university (Palizvan et al., 2013). Research that investigates best-practices on how to alleviate misconceptions

in health professions education is scarce.

Different educational and neuroscientific theories exist on the process of alleviating misconceptions, which is referred to as conceptual change. Conceptual Change Theory describes conceptual change as shifting away from a misconception towards the scientifically correct conception (Posner et al., 1982). Conceptual change is a process of accommodation during which misconceptions are reorganised or replaced by the scientific conception. However, no study found that a particular learner's conception was completely extinguished and replaced by the current scientific view (Duit & Treagust, 2012). Accordingly, neuroscientists have suggested that old ideas stay alive as they can be used in particular contexts (Mareschal et al., 2013). In the light of educational neuroscience, it would be interesting to investigate how concept learning comes about to be able to inform health professions education.

Concept learning is the subject of study in Chapter 4 to Chapter 6 of this thesis. In sum, these chapters describe explorative research on the origins of misconceptions, and an educational intervention aiming to enhance concept learning among students. The study described in Chapter 6 moves from educational practice to the neuroscientific laboratory. Here, educational research marries cognitive neuroscience to challenge the above-mentioned theories on concept learning.

· Metacognitive learning ·

"I am thankful for the brain that was put in my head. Occasionally, I love to just stand to one side and watch how it works." – R. Bolles

Metacognition is referred to as thinking about one's thinking (Flavell, 1979). Metacognitive learning as a component of self-regulated learning is gaining attention in our research community (Brydges & Butler, 2012; Gooding et al., 2017). Students are expected to become self-regulated learners which allows them to learn independently, effectively and lifelong (Group, 1996; Murdoch-Eaton & Whittle, 2012). Explicit teaching of metacognitive skills may help students to become more self-regulatory (Bjork et al., 2013). These skills include planning, monitoring, and evaluating one's actions (Zohar & Barzilai, 2013). However, explicit teaching of metacognitive skills in health professions education is scarce (Artino Jr et al., 2012). An additional problem is the low level of students' metacognitive knowledge, meaning they often do not know what they (do not) know (Thiede et al., 2003). This can become problematic for learning physiology concepts in particular, where misconceptions are often present unconsciously. Despite the recognised importance of metacognitive learning, research on metacognition with a focus on enhancing conceptual understanding is rather limited in health professions education.

Since metacognitive processes are suggested to be partly unconscious, they are difficult to investigate. Evidence is gathered by neuroscientists on brain areas that seem to drive metacognition, but there is still a large unknown area to be explored (Chua et al., 2014; Fleming et al., 2014). In the light of educational neuroscience, it would be of interest to gain insight in students' metacognition to guide future neuroscientific research.

Metacognitive learning is the subject of study in Chapter 7 to Chapter 10 of this thesis. The majority of studies focus on students' level of metacognitive knowledge. The final study, described in Chapter 10, maps students' metacognitive skills and perceptions on self-regulated learning in their medical curriculum.

· Through the lens of critical realism ·

"When you change the way you look at things, the things you look at change." – W. Dyer

To understand the nature of the research in this thesis one must realise that a scientist, including myself, always uses a specific lens while conducting research. This lens is one's research paradigm.

The bridge between neuroscientific research and educational research is difficult to cross, due to differences in philosophies about learning (Flobakk, 2015). One can look at learning as individual biological changes at a cellular level of the brain or rather as a social activity taking into account social interactions and the importance of context. The biological perspective is in line with the positivist paradigm of research, suggesting there is one true reality that can be observed. Positivism gives less consideration to social influences compared to existential aspects such as biochemical processes in the brain. On the other hand, the social perspective is in line with the constructivist paradigm of research, suggesting there are multiple realities that are constructed by people. Constructivism has a primary focus on social interactions and contextual features.

As I aim to emphasise both biological and social concepts, I take a post-positivism approach towards research (Bergman et al., 2012). The post-positivism paradigm suggests there is one truth, but it can never be truly observed (Phillips et al., 2000). This paradigm includes the ontological principles of critical realism (Collier, 1994). Critical realism provides a philosophical perspective that emphasises both social concepts and biological concepts, but without reducing one to the other. This is important, as educational neuroscience has an interdisciplinary endeavour at its heart (Flobakk, 2015). Educational neuroscience addresses questions that lay on the border between the social and the biological, so both biological and social explanations should be considered relevant. The philosophical position of critical realism can be located in-between positivism, viz. neurobiological mechanisms are predominant. and constructivism, viz. social context is predominant (Collier, 1994; Flobakk, 2015).

Regarding educational neuroscience, critical realism allows for different methods of studying learning that align with different perspectives of the biological and social world. In this thesis, I seek for ways to understand and improve learning, by considering the influences of biological processes and the influences of individual perceptions and contexts.

· Setting the scene ·

"I welcome truth. But I wish all of my facts to be in their proper context." – G. Hinckley

All studies in this thesis were conducted in the undergraduate curriculum at the Leiden University Medical Center. The 3-year program is a traditional curriculum mainly consisting of lectures, working groups and practical sessions. The study population comprises undergraduate students from different health professions: medicine, biomedical sciences, and clinical technology. In medicine, students focus on health prevention, and diagnosis and treatment of disease. In biomedical sciences, students specialise in cellular and molecular mechanisms of health and disease. In clinical technology, students learn about the technical aspects of healthcare. The undergraduate curricula have a strong focus on knowledge construction. Some studies in this thesis were carried out during undergraduate courses; 'mechanisms of disease' (Chapter 3), 'basis to homeostasis' (Chapter 4, 5, 9), 'human biology' (Chapter 7), and 'physiology, basic concepts' (Chapter 8). All studies took place between November 2016 and September 2019.

· Aim and outline of this thesis ·

The overall aim of this thesis is to improve health professions education by investigating spaced learning, concept learning and metacognitive learning using an educational neuroscience-inspired approach.

For spaced learning, we investigated how spaced learning is currently implemented in health professions education. Particularly, what spacing formats are being used? And do short spaces benefit knowledge retention?

For concept learning, we investigated how conceptual change comes about. Particularly, what are the origins of students' misconceptions? Are there effective instructional designs that may enhance conceptual understanding in medical physiology education? And is conceptual understanding mainly a matter of conceptual change or conceptual shift?

For metacognitive learning, we investigated students' use of metacognition, specifically in the context of physiology education where conceptual understanding plays a prominent role. How can we assess students' metacognitive evaluation?

Do students use metacognitive skills, i.e. planning, monitoring, evaluating, while solving physiology questions? And how do students perceive self-regulated learning in their medical school curriculum?

To fulfil our aims, we conducted nine studies with specific research questions, of which an outline is provided in Table 1. Chapter 11 summarises the main findings of the work outlined in this thesis. Additionally, findings are discussed and implications for educational practice and future research are provided.

Table 1 | Studied research questions and corresponding research methodology.

	Chapter	Research question	Research method
Spaced learning	2	How is spaced learning defined and applied in health professions education?	Scoping review
	3	Does the implementation of short spaces in a lecture enhance knowledge retention in students?	Experiment
Concept learning	4	What are the specific origins of inaccurate conceptual understanding among students regarding the interrelated concepts of pressure, flow, and resistance?	Content analysis
	5	Is cognitive inhibition involved in overcoming a physiological misconception?	Experiment
	6	Can peer instruction enhance students' comprehension of physiological concepts?	Experiment
Metacognitive learning	7	Can post-decision wagering be used as a measure of self-perceived knowledge in an educational context?	Experiment
	8	Can a multitier approach determine students' level of conceptual understanding by assessing their metacognitive evaluation?	Experiment
	9	Can refutation texts enhance students' cognition and metacognition regarding physiological concepts?	Experiment
	10	What are students' metacognitive competencies and what are their perceptions of self-regulated learning in the medical curriculum?	Thinking aloud & semi-structured interviews