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

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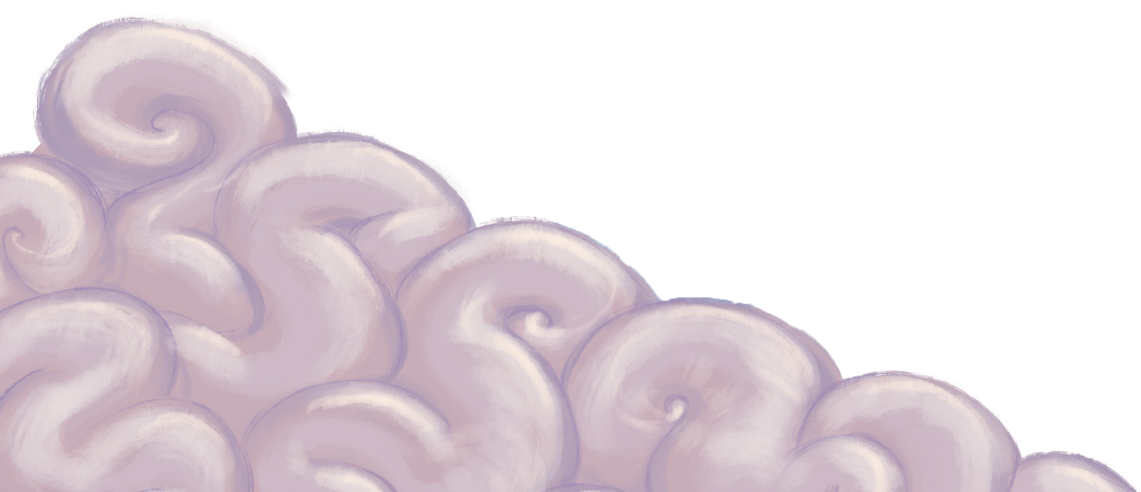
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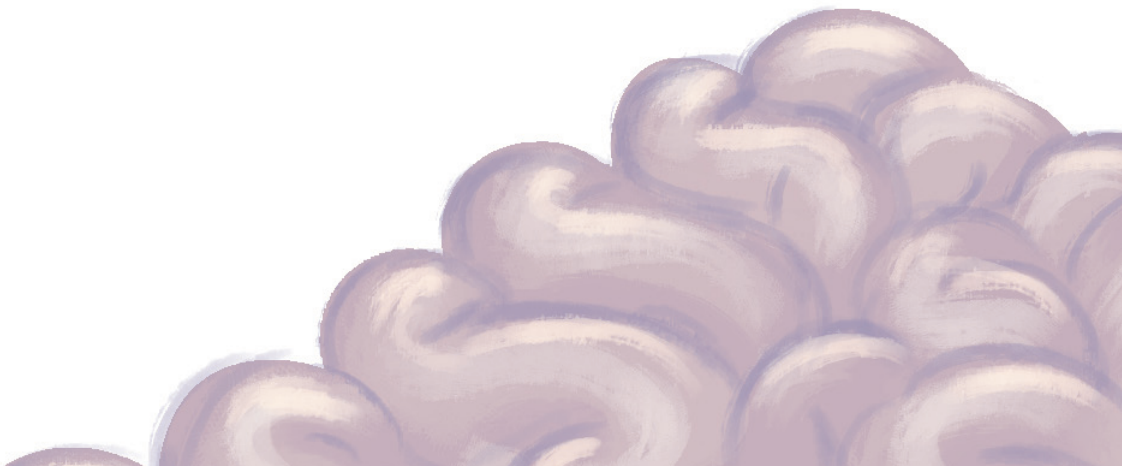
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Chapter 11



General discussion



· Purpose ·

Researchers and policymakers have acknowledged the need for evidence-informed curricula to support effective health professions education. Linking brain research to education research contributes to the development of such curricula by informing us on the science of learning. Namely, the brain influences learning, and learning influences the brain. This interplay between the brain and learning, also referred to as educational neuroscience, lies at the heart of the studies in this thesis.

The educational neuroscience-inspired research in this thesis focuses on three specific learning processes: spaced learning, concept learning, and metacognitive learning. Together, these learning processes are considered relevant as they are closely related to the fundamentals of Bloom's Taxonomy for establishing educational goals and to the educational goals of health professions' curricula.

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. This general discussion chapter elaborates on how this aim has been fulfilled. First, I provide the main findings for each learning process, including the implications for research and practice. Second, I provide my reflections on the methodology. Third, I discuss the way forward by addressing the potential of educational neuroscience-inspired research.

· Spaced learning: Finding the right time to learn ·

"Learning that is easy is like writing in sand, here today and gone tomorrow." - P. Brown.

By performing a scoping review, we discovered that spaced learning is finding its way to health professions education, although this mainly occurred over the last ten years (**Chapter 2**). This implies that the spacing effect, which dates back to 1885, needed more than a hundred years to transfer from cognitive psychology in order to make a substantial contribution to the health professions education literature (Ebbinghaus, 1885). Recent implementation might be a result of an increasing interest in online learning tools by early adopters (Rogers, 2003). These early adopters value the trialability attribute of innovations, resulting in a focus on improving educational practices and less on advancing theory or knowledge. Indeed, the majority of spaced learning literature in our community focuses on online settings. Perhaps this idea about early adopters also explains our finding that current definitions and applications of spaced learning often lack the necessary detail to support implementation or replication. Consequently,

we suggest that researchers - including early adopters - should base their studies on previous empirical research or theory to facilitate implementation and replication.

As an example, we designed a study in which the spacing format was based on neuroscientific theory (**Chapter 3**). Although our theory-informed spacing format did not enhance knowledge retention in medical students, we provided an informed and detailed study design that can still be used as a to-be-adjusted template by future researchers. Additionally, we implemented our format within a lecture setting, whereas most spaced learning research is conducted in online settings and simulation training. Our study may encourage researchers and educators to experiment with spaced learning in different educational settings, such as lectures or working groups.

We also learned an important lesson regarding the translation of a neuroscientific hypothesis to an educational environment: to carefully take into account the complexity of the environment. For instance, there are various ways to incorporate units of repetition in an educational setting, e.g. summaries or quizzes, whereas neuroscientific experiments always use an identical repetition mode, i.e. “high-frequency stimuli” (Smolen et al., 2016). Moreover, we used summaries as our repetition mode which can be classified as passive repetition, whereas the positive effect of spaced learning on knowledge retention may occur only when repetition is more actively practiced, such as with quizzes (Roediger & Butler, 2011).

To conclude, spaced learning research is need of clearly described applications to facilitate implementation and replication. While studying these applications, one should take into account - and be specific about - the characteristics of the study environment in order to determine if findings can be generalizable across educational contexts.

Practice points for researchers

- › Use a clear definition of spaced learning in describing your research in order to stimulate consistent application.
 - › Describe the study design thoroughly, using empirical research and/or theory.
 - › Experiment with spacing formats using different interstudy intervals, retention gaps, and forms of (active) repetition.
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Practice points for educators and policymakers

- › Further expand on the use of spaced learning in online settings and simulation settings, aiming to find optimal spacing formats.
 - › Start implementing spaced learning in different settings such as lectures or working groups, and evaluate the effects in your educational context.
-

· Concept learning: Know your misconceptions ·

“Nothing is more dangerous for a new truth than an old misconception.”- J. von Goethe.

We demonstrated that medical students have various misconceptions that hamper their understanding of physiological cardiovascular concepts such as ‘pressure’, ‘flow’, and ‘resistance’ (**Chapter 4**). Misconceptions are robust incorrect scientific beliefs that are difficult to alleviate as learners are generally unaware of their own misconceptions even after taking corresponding university classes (Chi et al., 1994a; Palizvan et al., 2013). With the help of educational theories on concept learning, we were able to categorise the misconceptions found in our study. This categorization may serve as a tool for educators to more precisely pinpoint misconceptions in their students and develop more effective instructions accordingly.

To know what such an instruction should entail, we investigated the underlying mechanism of (mis)understanding scientific concepts (**Chapter 5**). By measuring students’ brain activity using functional magnetic resonance imaging, we found significant activation of the putamen in misunderstanders (holding a misconception) compared with understanders (holding the scientific conception). This finding suggests a role for episodic memory in students holding a misconception. Although it is a long way from brain imaging to the development of instructional designs for educational practice (Howard-Jones et al., 2016), our findings may provide directions for concept learning in health professions education and other scientific disciplines. Based on the brain activity we found in the putamen, we support previous recommendations that focus on the crucial role of prior knowledge in teaching scientific concepts (Hewson & Hewson, 1983). Namely, a learner’s understanding is facilitated by adding new information to an existing mental model or schema in the brain, which comprises relevant prior knowledge a learner has already obtained (Alba & Hasher, 1983). Cognitive neuroscientists have shown that new information can be added to schemas, i.e. stable neural networks, faster when this information fits the prior knowledge (Van Kesteren et al., 2012). Thus, when a learner’s schema encompasses a misconception, it may be difficult for educators to teach the scientific conception using traditional teaching methods. Instructional designs for concept learning should therefore aim to disclose students’ prior knowledge and assumptions about the concept of interest.

An instructional design named peer instruction has demonstrated to facilitate conceptual understanding, potentially by disclosing students’ prior knowledge (**Chapter 6**). Peer instruction is a method that includes questions and subsequent discussion among peers (Mazur, 1997). The questions may activate students’

prior knowledge which they then make explicit to each other during the peer discussion. This mechanism may be effective not only for peer instruction, but also for other forms of interactive learning (Chi & Wylie, 2014). An interesting finding derived from this study is that even two initially incorrect peers can get to a correct answer together. This finding is in accordance with current literature and supports the idea of making one's thoughts explicit to another learner or the teacher, even if these thoughts are incorrect (Smith et al., 2009).

To conclude, students often have an inadequate level of conceptual understanding and educators may pinpoint students' misconceptions more easily by using categories. Additionally, both students and educators should acknowledge the importance of prior knowledge, and make this explicit, for example through interactive strategies. For peer instruction specifically, future research may take a qualitative approach which can provide additional insight in the reasoning processes of students and other valuable aspects of interactive instructional designs.

Practice points for researchers

- › Investigate the origins of misconceptions and misunderstandings in your discipline to direct educators towards the challenges in concept learning.
 - › Explore the underlying mechanisms of concept learning to advance knowledge on how conceptual understanding comes about.
 - › Use qualitative approaches to uncover the working mechanisms of interactive learning strategies and the role of prior knowledge in concept learning.
-

Practice points for educators and policymakers

- › Identify misunderstandings and misconceptions in your teaching - either empirically or by using literature/databases - and make them explicit.
 - › Aim to disclose students' prior knowledge and assumptions.
 - › Try interactive strategies such as peer instruction to improve students' conceptual understanding.
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· Metacognitive learning: Comfortably confident? ·

“Learning how to learn cannot be left to students. It must be taught.” - M. Gall

Across multiple studies, we found that students show difficulty estimating what they do (not) know, regarding conceptual knowledge specifically (**Chapter 7, 8, 9**). The ability to estimate one’s knowledge after performing a task or test is referred to as metacognitive evaluation (Zohar & Barzilai, 2013). We found that the multitier approach is an effective tool to obtain insight into students’ metacognitive evaluation ability (**Chapter 8**). Students took a multitier assessment in which a multiple choice question is paired with a confidence tier, i.e. 5-point Likert-scale (**Chapter 7**), as an indicator for students’ self-perceived knowledge. Although it is difficult to translate confidence to a numerical value, assessing confidence via the multitier approach appears an easy and effective way to diagnose students’ knowledge deficiencies. This is informative for both students and educators, since knowing that the level of conceptual understanding is insufficient is necessary for choosing to further study or teach this concept.

Besides a diagnostic tool, we also developed refutation texts as an intervention aimed at enhancing students’ metacognitive evaluation ability, and conceptual understanding accordingly (**Chapter 9**). A refutation text undermines a learner’s misconception by explicitly debunking it (Tippett, 2010). Although the refutation texts in our study did not significantly improve students’ cognition and metacognition, they provide an example of an intervention that is focused on enhancing metacognitive learning. Such interventions directed at improving metacognitive competencies are important to develop in health professions education, as they play a crucial part in the path towards an accurate conceptual understanding.

The studies in Chapters 7, 8 and 9 all raised similar questions: Why are students’ estimations of what they do (not) know inaccurate? Can this be attributed to inadequate metacognitive competencies additional to metacognitive evaluation? To answer these questions, we qualitatively explored the metacognitive competencies of medical students as they completed a conceptual learning task (**Chapter 10**). We found that students differed in their use of metacognitive skills, with an overall focus on monitoring and to a lesser extent on planning and evaluation. Although self-regulation, including metacognitive learning, is recognised by the medical education community as an important prerequisite for effective learning (Sandars & Cleary, 2011), it is a common incorrect assumption that such a skill is implicitly acquired (Bjork et al., 2013). Researchers have suggested that medical schools should specifically emphasise self-regulated learning, since development of self-regulation is a shared responsibility between both students and educators (Sandars

& Cleary, 2011). Based on our findings, we suggest they may focus on the use of planning and evaluation skills of students. Tanner (2012) has provided examples of self-questions that learners may ask in training their metacognitive skills, either on the level of an assignment, a single class session, an exam, or a full course. These questions are not only helpful for students, but also serve as a tool for educators who aim to address metacognitive skills explicitly in their classrooms.

It was worrisome to hear that some medical students felt no need for developing such metacognitive skills as they perceived medical education as an exercise in memorising facts. This remark calls for a medical curriculum reform in which more emphasis is laid on understanding, applying, analyzing, evaluating, and creating knowledge instead of remembering knowledge. Such a reform may enhance medical students' higher-order thinking skills and stimulate a lifelong attitude among our future doctors.

To conclude, educators may use various methods, e.g. multitier assessments and refutation texts, to facilitate (their insight in) students' metacognitive learning. Taking into account the metacognitive facets of learning - and teaching them to students explicitly - may help to enhance students' understanding of the subject matter. For our future medical doctors specifically, we may consider an undergraduate curriculum reform in order to facilitate a lifelong learning attitude.

Practice points for researchers

- › Take into account the metacognitive facets of learning when investigating conceptual understanding.
 - › Gain insight in students' metacognitive competencies and development thereof in their medical training, especially in the undergraduate curriculum.
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Practice points for educators and policymakers

- › Implement a multitier diagnostic test to gain more insight in students' level of knowledge and to pinpoint misconceptions.
 - › Integrate metacognition in the everyday discourse of the classroom to foster a metacognitive habit of mind, for instance by examining students' metacognitive evaluation or by using self-questions.
 - › Consider an undergraduate medical curriculum reform that is aimed at challenging students to develop their higher-order thinking skills and lifelong learning attitude.
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· Reflections on the methodology ·

“The only people who see the whole picture are the ones who step out of the frame.”

- S. Rushdie

Awareness of the overall strengths and limitations of this thesis is essential to value its results. This reflection is additional to the strengths and limitations of each study described in the individual chapters.

The overall methodological rigor is reflected in the use of different methods. Qualitative research methods were used to enrich quantitative research findings and vice versa. Furthermore, most studies were incorporated in authentic educational settings. This allowed us to investigate instructional designs that could be implemented relatively easy in the medical school curriculum if they were found to be effective. A limitation of this approach is that some of our studies were restricted by logistics related to the curriculum, such as time on task during the experiments.

In this thesis, I used critical realism as the philosophical grounding of our studies. I feel comfortably confident when arguing that critical realism is a suitable paradigm for research related to educational neuroscience. Critical realism allowed us to acknowledge the importance of both the natural and the social world (Collier, 1994). This is desirable for educational neuroscience-inspired research as its interdisciplinary nature requires a paradigm that goes beyond the philosophies of education sciences, psychology and neuroscience (Flobakk, 2015). No pre-dominance is given to outcomes from natural sciences or social sciences. For instance, contextual factors were discussed in our scoping review on spaced learning, as well as the potential influence of neuroscientific evidence on the development of new spaced learning formats. In all our studies, we aimed to continuously balance between the relevance of both natural and social factors and how these related to our research design and outcomes.

Critical realism also allowed us to use different methods to investigate different aspects of reality. This is illustrated by this thesis, which includes a variety of qualitative and quantitative methods, i.e. experiments, correlational methods, functional magnetic resonance imaging, semi-structured interviews, thinking aloud, and conventional content analysis. For future researchers, I would like to emphasise the value of using qualitative methods conjoined with quantitative methods, despite the fact that ontologically, the critical realist view on reality is post-positivistic. Some argue that a post-positivistic ontology does not allow for qualitative methods to be used. For example, Gill (2011) states that “one key assumption of qualitative research is that there is not one truth, but multiple truths.” This is often linked to the interpretivist epistemology saying that “the job

of qualitative researchers... is to acknowledge and report these different realities by relying on the voices and interpretations of the participants through extensive quotes, presenting themes that reflect the words and actions of participants, and advancing evidence of different perspectives on each theme.” (Wiltshire, 2018). Contrastingly, critical realists argue that qualitative research may be conducted in order to find the truth, by studying how individual experiences are made manifest by social conditions that are real and existing. Contexts can provide insight into generative mechanisms that may explain certain causalities (Sayer, 1992). As Maxwell (2012) writes, “while critical realism rejects the idea of ‘multiple realities’, in the sense of independent and incommensurable worlds that are socially constructed by different individuals or societies, it is quite compatible with the idea that there are different valid perspectives on reality.” Regarding qualitative methods, this claim permits researchers to move beyond an emphasis on subjective, interpreted experiences and towards uncovering how social relations generate such experiences.

· Educational neuroscience as a guiding principle ·

“If the human brain were so simple that we could understand it, we would be so simple that we couldn’t.” - E. Pugh

The overall aim of this thesis was to improve health professions education by investigating spaced learning, concept learning and metacognitive learning using an educational neuroscience-inspired approach. Here, I elaborate specifically on the potential of educational neuroscience.

Our studies illustrate that cognitive psychology and neuroscience may guide the development of educational interventions. Examples from cognitive psychology are: the post-decision wagering method, overt learning theory, and metacognitive theory. Additionally, neuroscience informed us on the use of spacing formats. Vice versa, we used educational theories as input for neuroscientific hypotheses to uncover the mechanisms of concept learning. Our fMRI study is an example of how educational neuroscience may also be used to answer fundamental research questions about the science of learning.

Overall, I argue that the value of educational neuroscience-inspired research lies in the interdisciplinary nature of the field and the open-minded view on collaborating with other disciplines. Furthermore, educational neuroscience has an urge to explain underlying mechanisms of behaviour and the field embraces the importance of flexibility in methods. I believe it is this combination of qualities that makes educational neuroscience a valuable addition to currently existing approaches in the health professions education research community.

Challenges

A researcher may face various challenges that should be taken into account when conducting educational neuroscience-inspired research. First, one may encounter criticism regarding the relevance of neuroscience for education. Some researchers are in favor of a pure psychology approach in order to understand the effect of education on (learning) behaviour (Bowers, 2016; Dougherty & Robey, 2018). However, psychological theories infer hidden causal mechanisms to explain behaviour. These hidden causalities can only be uncovered by studying the underlying brain mechanisms (Thomas, 2018). It is important to emphasise that there is value in going beyond behaviour and moving towards an understanding of the underlying mechanism to improve education, even when behavioural effects are already known (Thomas et al., 2019b):

“It was known 300 years ago that chewing the bark of the cinchona tree was effective in alleviating the symptoms of malaria. Via the extended contributions of the natural sciences, the U.S. Centers for Disease Control and Prevention now list a range of medicinal treatments for malaria. Understanding mechanisms can improve something that already works.”

Second, it can be difficult not to overinterpret or misinterpret the research findings, leading to conclusions that are too strong (de Bruin, 2016). For instance, it should be considered inappropriate to derive direct implications for teaching practices based on a fMRI study. Instead, translational research is needed on various levels such as the classroom and the curriculum, before one can provide adequate and evidence-informed advice about reforming educational practice. This includes taking into account contextual and political factors. So, keep in mind that conducting educational neuroscience-inspired research may not affect educational practice at first, which does not undermine the quality of the research itself (Gabrieli, 2016):

“Just as we do not value social neuroscience based on its impact on societal happiness, we should not value educational neuroscience on its ability to reform education.”

Third, it is important to be aware of the seductive allure of educational neuroscience. Various studies have shown that explanations of psychological phenomena are more satisfying to people when they contain neuroscientific information, even when this information is irrelevant (Weisberg et al., 2008). Many underlying reasons have been proposed for this effect. For example,

neuroscience may be associated with an apparent objectivity of measurements that are interpreted as more powerful evidence opposed to behavioural research. Or, neuroscience may depict a mind-brain connection that people implicitly believe not to exist (Weisberg et al., 2015). Aside from the possible reasons explaining this effect, the point is that a researcher should be aware that educational neuroscience is an approach, not a goal in itself to satisfy one's environment. The quality of research is not determined by the amount of neuroscience or cognitive psychology that is put into it. There are many examples of interdisciplinary research within different educational domains for instance, that are just as valuable: see also our studies on the multitier approach and refutation texts.

Opportunities

Besides the challenges, I will highlight several opportunities that I see for future educational neuroscience-inspired approaches in the health professions education context.

For the researcher

In this thesis, we focused our research on spaced learning, concept learning, and metacognitive learning respectively. I would encourage researchers to also consider other topics relevant to health professions education and that may benefit from an educational neuroscience approach. For instance, neuroscientific and psychological knowledge on reward and reinforcement may be helpful in educational research on student motivation and goal orientation. Other interesting topics to explore include cognitive load, emotion, stress, and visualisation (Friedlander et al., 2011).

For the educator

Educational neuroscience may help educators to understand and support students' learning behaviours. More firmly, it has been stated that "when teacher training does not include a scientific understanding of learning, this understanding and their practice suffers." (Howard-Jones et al., 2016). Interestingly, beneficial learning effects have been illustrated for learners that were taught about neuroplasticity⁶⁷. So, educational neuroscience can support learning directly by teaching about the learning brain, or indirectly by encouraging teachers to design interventions in the classroom based on neuroscientific and psychological evidence (Thomas et al., 2019b).

For the policymaker

Worldwide, policymakers are enthusiastic when it comes to making evidence-informed decisions about education based on neuroscientific and psychological knowledge about learning (Ansari et al., 2012; Tommerdahl, 2010). Neuroscience is sometimes even perceived as “a remedy for reversing falling standards in education by crafting an evidence base for education and a new learning of science.” (Carew & Magsamen, 2010). Hardiman (2012) claims that educational neuroscience may shift the focus of policymakers from the product of learning to the process of learning, since educational neuroscience is sharply focused on how learners learn. However, policymakers should be aware that this process of learning is highly complex and encompasses neurobiological, cognitive, societal, pedagogical, interactional and ethical aspects. Therefore, close collaborations with researchers and educators are desired. The researchers’ and educators’ communities have expertise in educational and social thinking which contributes to shaping educational goals.