



# Review on the Prevalence and Persistence of Neuromyths in Education – Where We Stand and What Is Still Needed

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The buzzword *brain-based learning* emerged in the 1970s and continues to fascinate teachers and learners in schools and universities today. However, what interested teachers often fail to realize is that *brain-based* or *brain-friendly learning* can not only be a plausible concept, but also a myth when applied incorrectly. Numerous empirical studies reveal a high degree of support for misconceptions about *learning and the brain*, known as neuromyths, among both pre-service and in-service teachers. When applied in the classroom, these myths can waste the educational system's money, time and effort. Even though the neuromyths issue has been known for two decades and the topic remains a focus of constant research, even today, the research discourse barely goes beyond replicating the earliest research findings. This review article provides an overview of the theoretical and empirical state of research on neuromyths. As part of this, ten neuromyths on the subject of *learning and memory* will be described in terms of content and the results of prior studies on neuromyths will be summarized. The overview of the theoretical and empirical state of research serves as a basis for highlighting controversies, fundamental concepts, issues and problems, current research gaps and potential developments in the field. Topics discussed include whether controversial research findings on correlations with endorsement of neuromyths are merely a methodological artefact, and why contradictions exist between the theoretical and empirical state of research. In addition, three central research gaps will be identified: First, studies should be conducted on whether and to what extent the endorsement of neuromyths really deprives teachers and students of opportunities to spend the education system's money, time and effort on more effective theories and methods. Second, there is too little work on developing and evaluating intervention approaches to combat neuromyths. Third, a standard scientific methodology or guidelines for determining new neuromyths are lacking. As desirable future developments in the field, more work educating people on neuromyths, uniform vocabulary, and interdisciplinary cooperation are highlighted. This contributes to answering the question of to what extent interweaving neuroscience, educational science and cognitive psychology can contribute to reducing the prevalence of neuromyths in education.

**Keywords:** neuromyths, neurodidactics, brain-based learning, brain-friendly learning, educational neuroscience, neuroeducation, MBE (mind, brain, and education science)

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## INTRODUCTION

Insights from brain research have resulted in a downright neuro-boom in recent years, expressed not only in transfer endeavors such as *neuro-marketing*, *neuro-architecture* and *neuro-management* (Grospietsch and Mayer, 2020), but also and primarily in various *neuro-education* or *neuro-didactics* publications for teachers and learning guides for students (e.g., Jensen, 1998; Sprenger, 2002; Doyle and Zakrajsek, 2013; Kagan, 2014; Grospietsch, 2021). *Brain-based* or *brain-friendly learning* is often treated as a magic word in schools, universities and other educational institutions (e.g., Jensen, 2008; Folta-Schoofs and Ostermann, 2019). “*Brain-based learning can change everything*”, “*Brain-friendly learning is a little gear that, when turned, unleashes a powerful effect*”, and “*When we teach children and youth how to learn in a brain-friendly way, we change the world*” are just a few of the promises made with respect to neurodidactics. However, interested teachers and learners often fail to consider that neurodidactics is more than just a plausible concept – it can also be a myth when applied incorrectly. For example, the promises above often go along with recommendations such as “*Our brain wants us to use all of it and not just a small fraction*”, “*Address both brain hemispheres in equal measure*”, or “*Pay attention to whether you are a visual, auditory or haptic learner*”. From a scientific perspective, so-called *neuromyths* can be found at the core of these deceptively simple recommendations (Organisation for Economic Co-operation and Development [OECD], 2002). Numerous empirical studies reveal widespread endorsement of such misconceptions on the topic of learning and the brain both among the public at large and among pre-service and in-service teachers (e.g., Dekker et al., 2012; Ferrero et al., 2016). Even school principals, award-winning teachers and university instructors widely endorse neuromyths like “*we only use 10% of our brains*”, “*learning differences due to hemispheric use*”, or the “*existence of learning styles*” (Horvath et al., 2018; Zhang et al., 2019). On the one hand, this is problematic because it could lead teachers to pass on incorrect content and/or ineffective learning strategies to their students. On the other hand, it could waste the education system’s “*money, time and effort*” (Dekker et al., 2012, p. 1) and deprive both teachers and learners of opportunities to expend resources on more effective theories and methods (e.g., teaching learning strategies or cognitive activation). This review article provides an overview of the theoretical and empirical state of research on neuromyths<sup>1</sup> and discusses controversies, fundamental concepts, issues and problems, current research gaps and potential developments in the field. It also seeks to gain insight into the question of to what extent interweaving neuroscience, educational science and cognitive psychology can contribute to reducing the prevalence of neuromyths in education.

<sup>1</sup>Articles involving theoretical descriptions of individual neuromyths and/or studies presenting empirical results are included. More general contributions on neuromyths (Papatzikis, 2017; Pasquinelli, 2012; Purdy, 2008; etc.) are excluded since this review aims at a closer focus on the topic.

## THEORETICAL STATE OF RESEARCH ON NEUROMYTHS

The term “neuromyth” was coined by the neurosurgeon Alan Crockard in the 1980s to describe scientifically inaccurate understandings of the brain in medical culture (Howard-Jones, 2010). The Organisation for Economic Co-operation and Development (Organisation for Economic Co-operation and Development [OECD], 2002) defines neuromyths as “*misconception[s] generated by a misunderstanding, a misreading, or a misquoting of facts scientifically established (by brain research) to make a case for use of brain research in education and other contexts*” (p. 111). Neuromyths have been identified with respect to various topics, such as indicators for specific learning difficulties like dyslexia (Macdonald et al., 2017) or the influence of nutrition (Dekker et al., 2012) and music (Düvel et al., 2017) on the brain. However, the lack of standardized methods for classifying misconceptions about learning and the brain as neuromyths and/or investigating new neuromyths remains an issue. Empirical studies often publish lists declaring various misconceptions to be neuromyths without defining the neuromyth construct more precisely, pointing out the logical fallacies at the root of the relevant misconceptions or juxtaposing them with their scientific refutations (e.g., Herculano-Houzel, 2002; Dekker et al., 2012). As a result, interested parties in the education system are unable to adequately inform themselves about neuromyths. Grospietsch (2019) made a first attempt to more precisely define scientific myths as a general construct. According to her, scientific myths exist on various topics in the natural sciences, including the iron content of spinach, an alleged link between vaccines and autism, or the effectiveness of the ‘blood type’ diet (Schaal, 2018). The widespread misconceptions that exist about the nature of science (McComas, 1998) can also be classified as scientific myths. Scientific myths can be created either by the general public or by scientists themselves (Bodenmann, 2009) when aspects of scientific argumentation and the nature of science are neglected. They can spread rapidly, can be highly resistant to change, and can be facilitated or strengthened by the following backfire effects (Grospietsch and Mayer, 2021a):

1. The mere mention of a memorable scientific myth can lead to its long-term retention (*familiarity backfire effect*).
2. Too many scientific arguments against a scientific myth can make the more simply formulated myth seem even more attractive (*overkill backfire effect*).
3. When people are strongly convinced of a scientific myth, their processing of counterarguments may be skewed, leading – whether consciously or unconsciously – to a further strengthening of the scientific myth (*worldview backfire effect*).

Based on this theoretical foundation regarding the *scientific myths* construct and a content analysis of neuromyths on the subtopic of *learning and memory*, Grospietsch (2019) came to define neuromyths as misconceptions based on a kernel of ‘truth’<sup>2</sup>, meaning that they take a scientific term or research finding (= *neurofact*) as a starting point for their argumentation,

<sup>2</sup>‘Truth’ is placed in quotes here because this term should not be understood to mean that scientific findings can ever be proven beyond all doubt (cf. Nature of Science).

which morphs into a no-longer-scientifically-accurate implication for teaching and learning (= *neuromyth*) through a series of erroneous conclusions and logical fallacies. The starting points for these fallacious lines of argumentation are findings from neuroscience or cognitive psychology. Although many theoretical descriptions of individual neuromyths exist that delineate certain individual arguments or counterarguments, only ten neuromyths have been systematically described with respect to their kernel of truth, individual erroneous conclusions and appropriate counterarguments (Grospietsch and Mayer, 2018; 2019; 2021a; 2021b; Grospietsch 2019). Only such systematic descriptions make it possible for recipients to grasp the fallacious lines of argumentation that underlie neuromyths. That is why the present article covers these ten neuromyths on the subtopic of *learning and memory* in detail. They are presented based on the systematic descriptions by Grospietsch and Mayer (2018, 2019, 2021a, b and Grospietsch 2019), which in turn follow the methodology of *scientific clarification* (Kattmann et al., 1997).

There is an abundance of theoretical descriptions of the neuromyth on the *existence of learning styles* (Looß, 2001; Geake, 2008; Pashler et al., 2008; Alferink and Farmer-Dougan, 2010; Lilienfeld et al., 2010; Adey and Dillon, 2012; Lethaby and Harries, 2016; Tokuhamma-Espinosa, 2018; Meinhardt, 2019; Newton and Salvi, 2020; Papadatou-Pastou et al., 2020). According to Grospietsch and Mayer (2021b), the kernel of truth behind this neuromyth is that people differ in the mode in which they prefer to receive information (visually or verbally; e.g., Höffler et al., 2017). The first erroneous conclusion that can be drawn from this kernel of truth is that there are auditory, visual, haptic and intellectual learning styles, as Vester (1975) suggested in the German context.<sup>3</sup> The next erroneous conclusion drawn is that people learn better when they obtain information in accordance with their preferred learning style. Finally, the third erroneous yet widely disseminated conclusion is that teachers must diagnose their students' learning styles and take them into account in instruction. In contrast, the scientifically accurate perspective is as follows: Vester's model of learning styles is not even logically consistent, because it compares three sensory channels to an 'intellectual' learning style (Looß, 2001). Tests of learning styles are unreliable from a measurement perspective and are unable to accurately categorize heterogeneous groups of learners (Coffield et al., 2004; Pashler et al., 2008). Four learning styles cannot even come close to describing learning processes, which are as individual as a fingerprint. Moreover, there is no empirical evidence confirming the effectiveness of considering students' learning styles in instruction (Willingham et al., 2015). Regardless of the mode in which it is presented, information must be meaningfully processed, repeated and elaborated. A balanced repertoire of learning strategies is important here (Newton, 2015; Lethaby and Harries, 2016). If a person feels that they learn best by writing the content down in their own words, this is

not because they then see what they have written down, but rather because *writing something down in one's own words* serves as an elaboration strategy (Grospietsch and Mayer, 2021b).

There are numerous theoretical descriptions and speculations about the origin of the neuromyth that *we only use 10% of our brains* (Beyerstein, 2002; Geake, 2008; Lilienfeld et al., 2010; Adey and Dillon, 2012; Jarrett, 2014; Tokuhamma-Espinosa, 2018). According to Grospietsch and Mayer (2019), the kernel of truth underlying this neuromyth is that contemporary imaging techniques can show which specific regions of the brain are involved in certain mental or physical activities. For example, many fMRI images exist in which only a portion of the brain is highlighted in color. The erroneous conclusion drawn from this kernel of truth is that only these highlighted regions are active and the gray-shaded regions are completely inactive. Other assumptions include the existence of a 'silent cortex' with no function at all and that only 10% of our brain consists of neurons, with the rest consisting of functionless glia cells. This leads to the erroneous conclusion that learners' brain capacity can and must be increased. In contrast, from a scientifically accurate perspective, fMRIs and other such images are based on differential imaging techniques, in which only regions that exceed a certain baseline level of activity are highlighted in color (Darvas et al., 2004). Even the grey-shaded regions are in a kind of 'standby mode' involving anticipatory activity (Whittingstall and Logothetis, 2009). Beck (2016) compares this to a football pitch: Just because one player has the ball, the other ten players on the team are not inactive. Likewise, allegedly 'silent' regions of the cerebral cortex belong to the association cortex and have important functions for higher-level psychological, psychosocial and mental abilities (Bear et al., 2016), and the ratio of neurons to glia cells is not 1:10 but actually about 1:1 (von Bartheld et al., 2016). Moreover, glia cells are not functionless. They take on important functions to support neurons and are also involved in memory formation (Hilgetag and Barbas, 2009).

Several theoretical descriptions of the neuromyth regarding *learning differences due to hemispheric use* also exist (Organisation for Economic Co-operation and Development [OECD], 2002; Becker, 2006; Geake, 2008; Alferink and Farmer-Dougan, 2010; Lilienfeld et al., 2010; Lindell and Kidd, 2011; Adey and Dillon, 2012; Jarrett, 2014; Tokuhamma-Espinosa, 2018). According to Grospietsch (2019), the kernel of truth underlying this neuromyth is that one brain hemisphere is more strongly involved in certain cognitive processes than the other (*hemispheric dominance*) (e.g., Ocklenburg et al., 2014; Bear et al., 2016). Based on this kernel of truth, it is erroneously concluded that the two brain hemispheres have different strengths and weaknesses. It is assumed that every person has a dominant hemisphere that they rely upon more strongly than the other, and that learners' (cognitive) characteristics are rooted in this 'hemispheric dominance' – misinterpreted as the strength of the two hemispheres. For example, analogously to the neuromyth that logic is located in the left hemisphere, creativity in the right (see below), it is allegedly the case that 'left brain dominant' learners are more talented in mathematics, while 'right brain dominant' learners

<sup>3</sup>For an international overview of prominent learning styles models, see Coffield et al. (2004).

are better able to complete creative tasks. Ultimately, the erroneous conclusion is drawn that learners cannot complete tasks that misalign with their hemispheric dominance or can do so only with great difficulty; thus, teachers need to take into account whether learners are *left-brained* or *right-brained* in their instruction. From a scientifically accurate perspective, however, it is learners themselves rather than brain hemispheres that possess different strengths and weaknesses rooted in their intelligence, use of learning strategies, interest, motivation, attention, etc. (Gruber, 2018). Hemispheric dominance merely means that one of the two hemispheres is more strongly involved in a specific cognitive process than the other. As will be explained in the next paragraph on the neuromyth that *logic is located in the left hemisphere, creativity in the right*, functions are lateralized only to a certain extent. Generally speaking, information is stored throughout the entire architecture of a given neural network and thus in memory traces (engrams) throughout the brain. As long as the corpus collosum, the band of nerves linking the two hemispheres, remains intact, a constant exchange of information between the two hemispheres takes place, regardless of the type of activity being conducted (Bear et al., 2016).

The neuromyth that *logic is located in the left hemisphere, creativity in the right* (e.g., Hines, 1991) exhibits some thematic overlap with the neuromyth concerning *learning differences due to hemispheric use*. The two neuromyths are frequently described in relation to one another (Organisation for Economic Co-operation and Development [OECD], 2002; Alferink and Farmer-Dougan, 2010; Tokuhama-Espinosa, 2018; Meinhardt, 2019). According to Grospietsch and Mayer (2019), the kernel of truth underlying this neuromyth is that the cerebrum contains two hemispheres that are not completely identical from an anatomical or functional perspective (*hemispheric asymmetry*; e.g., Jäncke, 2013; Ocklenburg et al., 2014). The neuromyth that *logic is located in the left hemisphere, creativity in the right* is based on this kernel of truth, yet taken to the erroneous conclusion that each hemisphere works autonomously and has a different function: The left hemisphere is responsible for intellectual, rational, verbal and analytical thinking, while the right hemisphere is responsible for creative, intuitive and non-verbal thought processes. It is further erroneously concluded that schools and society at large place too much emphasis on the left hemisphere, unduly straining this side of the brain. This leads to the recommendation that both hemispheres be addressed equally and interactions between them be facilitated. From a scientifically accurate perspective, however, the two hemispheres are linked to one another via the corpus collosum, as mentioned above (Bloom and Hynd, 2005). They work together on all processing tasks (Singh and O'Boyle, 2004), as can be illustrated with the example of language: The left hemisphere is predominant in many but not all verbal processes. A few components of language are processed in the right hemisphere, including intonation and reading between the lines (Lai et al., 2015). Thus, the process is not completely lateralized (Nielsen et al., 2013).

A further neuromyth related to the relationship between the brain hemispheres concerns the *effectiveness of Brain Gym*

(Becker, 2006; Hyatt, 2007; Stephenson, 2009; Howard-Jones, 2010; Adey and Dillon, 2012; Tokuhama-Espinosa, 2018). According to Grospietsch and Mayer (2021a), the kernel of truth underlying this neuromyth is that a crossed neural pathway links the left hemisphere of the brain to the right side of the body and vice versa (e.g., De Lussanet and Osse, 2012; Kinsbourne, 2013). Based on this kernel of truth, it is erroneously concluded that motor problems during cross-body coordination exercises result from a lack of coordination between the two hemispheres. Learning difficulties are also said to result from a lack of cooperation between the two hemispheres. It is further erroneously concluded that cooperation between the two hemispheres can be improved by increasing the number of synaptic connections between them and that cross-body coordination exercises can improve one's mental abilities. Ultimately, it is claimed that 'Brain Gym' programs available for sale can prevent learning difficulties, improve students' learning or creativity, and even raise their intelligence. From a scientifically accurate perspective, however, the two brain hemispheres are constantly exchanging information in coordination with one another as long as the corpus collosum, the band of nerves linking the two hemispheres, remains intact (Blais et al., 2018). Learning difficulties are instead attributable to differences in working memory capacity or processing speed (Willcutt et al., 2013). They can also be caused by a lack of attention, unfavorable motivational conditions, or deficits in the use of learning strategies (Creß and Friedrich, 2000; Grube and Ricken, 2016). We cannot consciously influence where synapses arise, and their formation is not a unique occurrence. New synaptic links form during each and every cognitive process (Zheng et al., 2013). While coordination exercises can improve students' physical fitness levels and motor skills, they do not improve their cognitive performance (Cancela et al., 2015). Any subjectively or objectively perceived cognitive improvements result instead from the break from learning/improved circulation that accompanies such exercises (Budde et al., 2008).

The neuromyths that *the best learning occurs before age three* and that there are *critical time periods for learning* are likewise tightly interwoven with one another and often described together (Bruer, 2000; Organisation for Economic Co-operation and Development [OECD], 2002; Organisation for Economic Co-operation and Development [OECD], 2005; Alferink and Farmer-Dougan, 2010; Howard-Jones 2010; Adey and Dillon, 2012). According to Grospietsch and Mayer (2020), the kernel of truth underlying the notion that *the best learning occurs before age three* (e.g., Bruer, 2000; Tokuhama-Espinosa, 2018) is that the number of neural connections in the brain increases massively during the first years of life (e.g., Bianchi et al., 2013; Carter, 2014). Based on this kernel of truth, it is erroneously concluded that more synaptic connections in the brain is equivalent to a high level of intelligence. It is further assumed that adults' brains function worse than children's brains and that all structural changes as we age are negative. The erroneous conclusion drawn from this is that brain development can and must be influenced during early childhood (Organisation for Economic Co-operation and Development [OECD], 2002). From a scientifically accurate perspective, however, particularly intelligent people are actually

characterized by a reduced number of neural connections (Genç et al., 2018). Likewise, structural differences between children's and adults' brains have nothing to do with their quality of learning (Geerligs et al., 2015). Young people can process new information more quickly and efficiently in smaller, more differentiated networks, while older people process new information in broader, better linked neural networks (Organisation for Economic Co-operation and Development [OECD], 2002). Moreover, structural changes during adulthood are not necessarily negative: For example, prefrontal cortex development and myelination (in which the axons of nerve fibers are encased in myelin) continue until age 30, meaning that only adults are fully capable of well-thought-out reactions and moral decision-making (Carter, 2014) and able to more quickly and efficiently transfer information across far-flung regions of the brain (Spear, 2013). Furthermore, we cannot deliberately influence either the overproduction of synapses during early childhood or their subsequent pruning in favor of strengthening other types of neural connections that increase the neural network's efficiency (Casey et al., 2000; Bianchi et al., 2013).

The kernel of truth underlying the neuromyth concerning *critical time periods for learning* (Howard-Jones, 2010; Adey and Dillon, 2012; Tokuhama-Espinosa, 2018), according to Grospietsch and Mayer (2020), is that certain things can be learned more easily during particular sensitive phases during childhood (Thomas and Johnson, 2008; Carter, 2014). Based on this kernel of truth, it is erroneously concluded that children are capable of unlimited learning during their first years of life. It is also assumed that the construction of neural connections (synapses) can be facilitated by exposing children to the 'right' stimuli (e.g., reading aloud). Thus, it is claimed that exposure to certain 'special' stimuli in early childhood (e.g., classical music) leads to higher cognitive performance in adulthood (e.g., mathematical thinking). Children must therefore be presented with as many 'good' stimuli as possible during this time window, which then closes irrevocably, in order to avoid lifelong learning impairments that cannot be corrected later through education. From a scientifically accurate perspective, however, while it is true that children learn many new things in their first years of life (crawling, standing, walking, speaking, etc.), they do not possess 'unlimited learning capacity' (Bruer, 1997; Bruer, 2000). Learning is not determined by stimuli themselves, but by how they are processed. In general, when and how neural connections form cannot be deliberately controlled, and in fact, the neural network changes with every stimulus that is processed (Bear et al., 2016). No neuroscientific studies have ever demonstrated that long-term exposure to certain stimuli such as music has a positive influence on the brain (Perani et al., 2010) or that certain abilities can only be learned during a critical time window that opens at a certain time and later closes permanently (Thomas and Johnson, 2008; Howard-Jones, 2014). Negative consequences (in the sense of irreversible damage) are only a risk when complete deprivation of all stimuli takes place. For example, the central visual pathway cannot develop in the absence of visual stimuli (Bear et al., 2016). However, such cases are a very rare exception (Bruer, 1997; Bruer, 2000).

The neuromyth on *learning while you sleep* is theoretically described much more rarely compared to the aforementioned

neuromyths (Centre for Educational Research and Innovation [CERI], and Organisation for Economic Co-operation and Development [OECD], 2007; Lilienfeld et al., 2010; Tokuhama-Espinosa, 2018). Based on the kernel of truth (Grospietsch and Mayer, 2019) that nighttime restructuring (consolidation) processes in the brain can lead to new insights, one might erroneously conclude that people can learn completely new content while they sleep; they can use the time they spend sleeping for learning by exposing themselves to acoustic stimuli. This leads to the recommendation that learners should play audio files (e.g., vocabulary words in a new language) while they sleep. From a scientifically accurate perspective, however, information is encoded when a person is awake, and consolidated while they sleep. Both processes are necessary to store knowledge in long-term memory – in other words, to learn (Gais and Born, 2004). It is not possible to learn new content while one sleeps (Stickgold, 2012). Encoding new information during sleep would disturb the consolidation process for information encoded earlier (Gais and Born, 2004). During sleep, the brain is relatively strongly sealed off from the outside world (Muzet, 2007), although it can react to sensory inputs like smells by modifying the intensity of breathing (Stickgold, 2012), making conditioning possible (Arzi et al., 2012).

A further neuromyth that tends to be described in research on school students' (mis)conceptions is the *existence of specific storage locations (hard drive)* in the brain (cf. Schletter and Bayrhuber, 1998). According to Grospietsch (2019), the kernel of truth underlying this neuromyth is that the cerebrum contains various cortical regions with a functional division of tasks. From this, it is erroneously concluded that a kind of map can be drawn showing what is stored or processed where in the brain and what functions this entails. Thus, it is assumed that each region of the cerebral cortex functions as an autonomous center for certain tasks, with fixed regions responsible for topics such as mathematics. The conclusion drawn from this is that a single center for mathematics, for instance, exists in the brain that can be addressed in a targeted way. From a scientifically accurate perspective, however, as was the case for the neuromyth that *we only use 10% of our brains*, the corresponding research findings are based on differential imaging and depict an augmented but not complete division of tasks. Different regions of the brain are not isolated 'islands'; they communicate, influence and work together with one another (Anderson, 2010). Information is always processed and stored in parallel in multiple locations of the brain (LeDoux, 2007).

A neuromyth that has to date largely been addressed in the context of cognitive psychology and 'desirable difficulties' (e.g., Bjork and Bjork, 2011; Lipowsky et al., 2015) is the notion that *blocked learning is better than interleaved* (Grospietsch and Mayer, 2019). According to Grospietsch (2019), the kernel of truth underlying this neuromyth is that instructional designs in which the learning content is systematically structured facilitate positive learning effects among students (e.g., Hattie, 2009). From this, it is erroneously concluded that students become overwhelmed when instructional topics are not taught one after another in a structured, sequential way. A related assumption is that students' knowledge acquisition is more sustainable when the learning process is simplified, and quick and easy success during

learning improves students' long-term retention of the learning content. Thus, it is recommended that teachers follow the structure of school textbooks and teach topics one after another chronologically. From a scientifically accurate perspective, however, students who engage in interleaved learning (mixed, juxtaposed learning of different topics) have better scores on long-term performance tests (after several weeks or months have passed) and develop fewer misconceptions than students who sequentially learn content on one topic after another (e.g., Rohrer and Taylor, 2007; Ziegler and Stern, 2014). Research findings on desirable difficulties demonstrate the positive effects on students' knowledge acquisition of deliberately making learning processes more difficult (e.g., Bjork and Bjork, 2011; Dunlosky et al., 2013; Lipowsky et al., 2015) and that interleaved learning is superior to blocked learning in the long term (e.g., Mayfield and Chase, 2002). Cognitively demanding activities result in slow, not immediately visible learning successes, yet improve long-term retention of what has been learned (e.g., Carvalho and Goldstone, 2014; Bjork and Kroll, 2015).

Apart from the studies applied by Grospietsch and Mayer (2018, 2019, 2021a, b and Grospietsch 2019) to provide a *scientific clarification* (Kattmann et al., 1997) of the aforementioned neuromyths, few further theoretical descriptions of other neuromyths exist (e.g., in Jarrett, 2014; Beck, 2016; Tokuhama-Espinosa, 2018). Beyond the subtopic of *learning and the brain*, the best described neuromyths concern *multiple intelligences theory* (Geake, 2008; Howard-Jones, 2010), the consumption of sugary snacks and drinks (Howard-Jones, 2010) and water (Dündar and Gündüz, 2016). There is also extensive work on *psychological myths* (e.g., Lilienfeld et al., 2010), to which the aforementioned neuromyths *we only use 10% of our brains*, *learning differences due to hemispheric use* (McCarthy and Frantz, 2016) and *existence of learning styles* (Menz et al., 2020) can also be considered to belong.<sup>4</sup> For other cases, such as the myth that our *genetically determined number of cells determines learning success* (examined in a study by Bellert and Graham, 2013), the theoretical state of research must be considered highly deficient.

## EMPIRICAL STATE OF RESEARCH ON NEUROMYTHS

Numerous empirical studies<sup>5</sup> reveal that even though pre-service and in-service teachers as well as university instructors exhibit great interest in neuroscience, they are unable to differentiate neuromyths from "neurofacts"<sup>6</sup> (Grospietsch and Mayer, 2020). Studies demonstrating endorsement of neuromyths among in-service teachers have been conducted in England (Dekker et al., 2012; Simmonds, 2014; Horvath et al., 2018), the Netherlands

(Dekker et al., 2012), Switzerland (Tardif et al., 2015), Italy (Tovazzi et al., 2020), Spain (Ferrero et al., 2016), Portugal (Rato et al., 2013), Greece (Deligiannidi and Howard-Jones, 2015), Turkey (Karakus et al., 2015), Morocco (Janati Idrissi et al., 2020), China (Pei et al., 2015), Australia (Bellert and Graham, 2013; Horvath et al., 2018), Canada (Lethaby and Harries, 2016; Blanchette Sarrasin et al., 2019), United States (Lethaby and Harries, 2016; Macdonald et al., 2017; Horvath et al., 2018; van Dijk and Lane, 2018) and Latin America (Herculano-Houzel, 2002; Bartoszeck and Bartoszeck, 2012; Gleichgerrcht et al., 2015; Hermida et al., 2016; Varas-Genestier and Ferreira, 2017; Bissessar and Youssef, 2021). Studies demonstrating endorsement of neuromyths among pre-service teachers have been conducted in England (Howard-Jones et al., 2009; McMahon et al., 2019), Germany (Düvel et al., 2017; Grospietsch and Mayer, 2018; 2019), Switzerland (Tardif et al., 2015), Austria (Krammer et al., 2019; 2020), Slovenia (Škraban et al., 2018); Spain (Fuentes and Risso, 2015), Greece (Papadatou-Pastou et al., 2017), Turkey (Dündar and Gündüz, 2016; Canbulat and Kiriktas, 2017), South Korea (Im et al., 2018), Australia (Kim and Sankey, 2017), United States (Ruhaak and Cook, 2018; van Dijk and Lane, 2018) and Latin America (Herculano-Houzel, 2002; Falquez Torres and Ocampo Alvarado, 2018). The majority of such studies focus on pre-service and in-service teachers across all subjects and school types. Their findings consistently show that pre-service and in-service teachers endorse a large number of neuromyths, despite some (country-specific<sup>7</sup>) differences in the endorsement of certain individual myths (Grospietsch and Mayer, 2020). The hypothesis that cultural differences between countries influence which neuromyths gain currency where has taken hold in the research discourse (e.g., Pei et al., 2015; Ferrero et al., 2016; Hermida et al., 2016), even though this has not yet been systematically tested.

A few studies on neuromyths investigate specific groups such as post-graduate teacher trainees (Howard-Jones et al., 2009), pre-service special education teachers (Ruhaak and Cook, 2018), school principals (Zhang et al., 2019), or pre-service music (Düvel et al., 2017) and biology teachers (Grospietsch and Mayer, 2018; Grospietsch and Mayer, 2019). Comparisons of different groups are undertaken by Canbulat and Kiriktas (2017), Dündar and Gündüz (2016), Düvel et al. (2017), Gleichgerrcht et al. (2015), Herculano-Houzel (2002), Horvath et al. (2018), Macdonald et al. (2017), Simmonds (2014), Tardif et al. (2015) and van Dijk and Lane (2018). Macdonald et al. (2017) show that members of the general public endorse neuromyths more frequently than educators and persons with high neuroscience exposure. Herculano-Houzel (2002) likewise identifies a significant difference between the general public and neuroscientists. Her study finds differences between high school respondents, college respondents, graduate respondents, psychology students and neuroscientists (listed in order of decreasing endorsement of neuromyths). According to Gleichgerrcht et al. (2015) and van Dijk and Lane (2018), university professors and instructors in the

<sup>4</sup>This review will not further report on studies concerning *psychological myths*.

<sup>5</sup>This review includes all studies on the keyword "neuromyths" found via ERIC, PubMed and ResearchGate up to May 2021, that underwent peer review and/or were reviewed in such studies.

<sup>6</sup>This term is used in many studies of neuromyths. However, it is problematic from a *nature of science* perspective, since the natural sciences cannot yield 'proven' facts, but only ever preliminary results.

<sup>7</sup>Howard-Jones (2014) compares seven neuromyths across five countries in four cited studies.

field of teacher education exhibit slightly lower endorsement of neuromyths compared to (pre-service) teachers. In a study by Canbulat and Kiriktas (2017), in-service teachers endorse neuromyths slightly less frequently than pre-service teachers. These findings contradict those by Tardif et al. (2015), who found stronger endorsement of many neuromyths among in-service teachers. Zhang et al. (2019) and Horvath et al. (2018) demonstrate that even school principals and award-winning teachers endorse neuromyths with a high frequency. With the exception of the aforementioned differences, empirical findings on the prevalence of neuromyths can be considered quite consistent: Neuromyths are not sufficiently disavowed – particularly among teachers and university instructors, who are frequently assumed to be professionals in teaching and learning. Endorsement of the neuromyths on the *existence of learning styles* and the *effectiveness of Brain Gym*, which have found their way into learning guides and educational programs, is particularly high among these two groups as well as all other studied groups (Grospietsch and Mayer, 2020).

Tardif et al. (2015) demonstrate that (pre-service) teachers come into contact with neuromyths and associated practices during both their academic and practical training. A study by Howard-Jones et al. (2009) confirms that 56–83% of pre-service teachers encounter educational programs rooted in neuromyths during their first year of practical training in schools, which is associated with a high level of acceptance of these myths. Simmonds (2014) shows that many teachers use or have used unproven techniques such as Brain Gym in their instruction. Lethaby and Harries (2016) and Blanchette Sarrasin et al. (2019) provide evidence that many teachers who endorse neuromyths also employ instructional practices linked to these misconceptions in their classrooms (this is the case more frequently among preschool and elementary school teachers than secondary school teachers). Grospietsch and Mayer (2019) found a small positive association between endorsement of neuromyths and constructivist beliefs about teaching and learning. This association might indicate that highly engaged, innovative teachers are the ones who make a well-intentioned effort to incorporate ostensibly neurodidactic principles into their instruction. Conversely, Ruhaak and Cook (2018) show that teachers with accurate conceptions regarding neuromyths are more likely to employ effective instructional practices rather than ineffective ones based on neuromyths. Horvath et al. (2018) rightly criticize that the association between endorsement of neuromyths and teaching effectiveness has not yet been sufficiently investigated to conclude that endorsement of neuromyths has (negative) consequences for the education system. Nevertheless, their finding that non-award-winning teachers do not differ from award-winning teachers in their endorsement of neuromyths also does not allow conclusions to be drawn as to whether inaccurate content and/or ineffective learning strategies are being passed on to learners and/or the education system's "money, time and effort" (Dekker et al., 2012, p. 1) are being wasted on the implementation of neuromyths.

Research results on the factors affecting endorsement of neuromyths are diverse. Ferrero et al. (2016) show that reading pedagogical magazines increases endorsement of neuromyths. In contrast, Düvel et al. (2017) find that reading a large number of pedagogical books, magazines and websites reduces endorsement of neuromyths. Similarly, Macdonald et al.

(2017) and Ferrero et al. (2016) find that reading scientific articles reduces endorsement in neuromyths. Conversely, Gleichgerrcht et al.'s (2015) findings suggest that neither popular science nor neuroscientific articles sufficiently reduce beliefs in neuromyths. Papadatou-Pastou et al. (2017) identify general knowledge about the brain as the best "safeguard against believing in neuromyths" (p. 1). This is confirmed by studies by Howard-Jones et al. (2009) and van Dijk and Lane (2018). Nevertheless, in many studies, teachers who endorse scientifically appropriate conceptions about the brain to a high degree are more susceptible to believing in neuromyths (e.g., Dekker et al., 2012; Ferrero et al., 2016). Findings with respect to relevant personal characteristics are similarly diverse. The majority of studies find no associations between endorsement of neuromyths and age, gender, job experience, school subject, school type, school location (urban/rural) or completion of professional development courses (e.g., Dekker et al., 2012; Rato et al., 2013; Karakus et al., 2015; Papadatou-Pastou et al., 2017). Macdonald et al. (2017) show that a lower age, university degree and enrollment in neuroscience courses reduce but do not eliminate endorsement of neuromyths. Canbulat and Kiriktas (2017) and Ruhaak and Cook (2018) come to similar conclusions. Four studies report an association between endorsement of neuromyths and gender. In two of these studies, male teachers are more likely to believe in neuromyths (Canbulat and Kiriktas, 2017; Macdonald et al., 2017), while in the other two studies, their results are better than those for female participants (Dündar and Gündüz, 2016; Ferrero et al., 2016).

While the existing literature on neuromyths calls for integrating more neuroscience into teacher education (e.g., Howard-Jones, 2014), this alone does not seem sufficient to reduce pre-service and in-service teachers' misconceptions on the topic of learning and the brain. Although Dündar and Gündüz (2016) find that pre-service science teachers significantly outperform pre-service teachers of other subjects, findings by Macdonald et al. (2017) and Im et al. (2018) indicate that merely enrolling in neuroscience or psychology courses during university teacher education does not sufficiently reduce beliefs in neuromyths. Indeed, Grospietsch and Mayer (2019) find that even pre-service biology teachers, for whom neuroscientific content is part of their studies (e.g., courses in human biology and animal physiology), endorse neuromyths to a great extent. Moreover, in their study, endorsement of neuromyths was largely independent of the pre-service teachers' professional knowledge as well as theory-based and biography-based learning beliefs. Respondents in different stages of their training (first-semester students, advanced students and post-graduate teacher trainees) differed only with respect to their endorsement of scientifically accurate conceptions<sup>8</sup>, not in their endorsement of neuromyths. Given that biology teachers need to not only be able to address the topic of learning and the brain as instructional content but also use it to guide their students' learning processes, the (mis)conceptions found among pre-service biology teachers up to and including the

<sup>8</sup>Meant here is what is captured in almost all neuromyths studies with a scale on "neurofacts". An example item is *We use our brains 24 h a day*. For more information, see e.g., Dekker et al. (2012).

post-graduate teacher training phase must be considered deficient. Grospietsch and Mayer (2019) findings further suggest that misconceptions are resistant to traditional teacher education, which means that new teachers enter the practice with misconceptions despite their acquisition of professional knowledge.

Grospietsch and Mayer (2021a) show that university students make not only scientific (neuroscientific and cognitive psychological) arguments in favor of neuromyths but also biographical arguments based on their personal experiences. Moreover, refutation can actually bolster their misconceptions (= worldview backfire effect, see theoretical state of research). Indeed, university students mention many more erroneous conclusions and arguments in favor of neuromyths that previously assumed theoretically. Work by Petitto and Dunbar (2004) demonstrates that university students can stubbornly cling to their original misconceptions in the face of empirical demonstrations and theoretical accounts. Newton and Miah (2017) and Rousseau and Brabant-Beaulieu (2020) confirm this specifically with respect to the neuromyth on the existence of learning styles. According to a study by Kim and Sankey (2017), pre-service teachers may have come into contact with neuromyths even before beginning their studies, during their own time at school. They can be quite convinced of their misconceptions as a result of their practical experiences or consider them to be intuitively correct (cf. Blanchette Sarrasin et al., 2019). These are all potential reasons why there are currently few effective interventions to combat neuromyths (Grospietsch and Mayer, 2018, 2021a; McMahon et al., 2019). Findings by Grospietsch and Mayer (2018) show that even a university course imparting professional knowledge from the fields of cognitive psychology, neuroscience and biology education on the topic of *learning and the brain* in a deeply interlinked way is not sufficient for students to critically engage with neuromyths. Explicitly addressing, refuting and encouraging students to reflect on their own misconceptions – as can be the case when using conceptual change texts (on seven neuromyths, published in Grospietsch and Mayer, 2021b) – is necessary to sustainably reduce them. Instructional strategies and methods that take up students' misconceptions, deliberately provoke a *cognitive conflict*, and then systematically expand them in the direction of scientifically accurate concepts have been found to be particularly effective at combating neuromyths (Grospietsch and Mayer, 2018; 2021a). Howard-Jones (2014), Grospietsch and Mayer (2020) and Torrijos-Mualas et al. (2021) provide first (systematic) reviews of the state of empirical research on neuromyths.

## DISCUSSION AND OUTLOOK

### Controversies, Fundamental Concepts, Issues, and Problems in the Research Field of Neuromyths

This article has summarized the state of theoretical and empirical research on neuromyths. The first controversial aspect that can be identified is that many research findings on correlations with endorsement of neuromyths contradict one another. According

to Krammer et al. (2019), these contradictory findings could be a methodological artifact, as most existing studies applied Dekker's et al., (2012) instrument and uncritically assumed the unidimensionality of all specified neuromyths (an exception is Macdonald et al.'s, 2017). The response format applied (Yes/No/I don't know) has been also criticized from a methodological perspective (Krammer et al., 2019). Grospietsch and Mayer (2019) developed an instrument that asks respondents about neuromyths solely on the subtopic of *learning and memory* and applies a Likert scale, in accordance with Macdonald et al.'s (2017) recommendations. Tovazzi et al. (2020) recently developed an instrument for a few neuromyths that focuses more on procedural rather than declarative knowledge. Ultimately, however, these contributions have been seldom adopted, and new empirical studies and systematic reviews largely pass on the results and instruments that (continue to) shape the current state of research (e.g., Torrijos-Mualas et al., 2021).

Another aspect that can be considered controversial is that the theoretical state of research on neuromyths (*What assumptions do we have about how pre-service and in-service teachers argue in favor of neuromyths?*) contradicts Grospietsch's and Mayer's, (2019) empirical results (*What fallacious arguments are actually employed?*). In this study, pre-service teachers named many more arguments for neuromyths than previously assumed theoretically, and the neuromyth items that dominate the research discourse evoked very different associations for the participants. Grospietsch and Mayer (2019) critically conclude on the basis of their theoretical work on neuromyths that instruments need to more consistently ask questions about neuromyths' kernel of 'truth', individual erroneous conclusions, and the specialized knowledge needed to refute them. This could deliver more detailed starting points for interventions while simultaneously reducing the risk of failing to recognize that certain neuromyths build or rely upon one another and thus including them multiple times (cf. Krammer et al., 2019). Furthermore, Grospietsch and Mayer (2019) and Torrijos-Mualas et al. (2021) call for more (qualitative) studies of neuromyths in order to learn more about their genesis and causes and capture their 'actual' and not merely theoretically assumed chains of erroneous conclusions (see Theoretical State of Research) in greater detail (e.g., Newton and Salvi, 2020; Papadatou-Pastou et al., 2020).

### Current Research Gaps

Alongside the aforementioned methodological critique of the research field concerning *neuromyths* and the areas for further research presented here, our presentation of the theoretical and empirical state of research allows for the identification of three central research gaps that should shape the research discourse in the coming decade. First, studies should be conducted on whether and to what extent the endorsement of neuromyths really deprives teachers and students of opportunities to spend the educational system's money, time and effort on more effective theories and methods (e.g., teaching learning strategies or cognitive activation). Horvath et al. (2018) criticize that there is currently only speculation on this point and perhaps an unjust 'over-dramatization'. Second, this review article demonstrates that neuromyths remain a subject of attention almost two decades after they were first defined. However, even though the problem



has been known for so long, there has been relatively little work on developing and evaluating intervention approaches (e.g., Grospietsch and Mayer, 2018, 2021a; McMahon et al., 2019). The majority of neuromyth studies are fundamentally content to replicate 'old' findings on neuromyths, even though many other studies – sometimes from the same country – show that developing university courses and professional development opportunities for in-service teachers that are able to sustainably reduce endorsement of neuromyths represents a much more important goal (e.g., Craig et al., 2021). The third research gap that can be identified based on this review is that there is no standard scientific methodology or guidelines for determining new neuromyths, as was also corroborated by Torrijos-Muelas et al. (2021). Although recent work by Grospietsch and Mayer (2018; 2019; 2021a; 2021b) and Grospietsch (2019) has contributed to a more detailed classification of *scientific myths* and *neuromyths*, many open questions remain, such as: What level of endorsement does a neuromyth need to enjoy in order to be categorized as such? Put bluntly: Are misconceptions on the topic of learning and the brain held by no one or by only a single person really neuromyths? The example a *genetically determined number of cells determines learning success* (examined in a study by Bellert and Graham, 2013) demonstrates that studies have examined neuromyths for which theoretical descriptions and justifications for their classification as part of a *neuromyth construct* are lacking. The problem we wish to point out is this: Who is actually ensuring that we are not simply including alleged neuromyths in our research without critical examination and with what methods? Based on this review, we call for classifying neuromyths as *scientific myths*, meaning a specific kind of misconception (Grospietsch and Mayer, 2021a), in a theoretically-driven way, by deriving clearly defined criteria (for example, see the definition by Grospietsch, 2019). Otherwise, one might oneself unwittingly generate or spread a *neuromyth*.

## Potential Developments in the Field

This review has made clear that there is a need for future researchers to further clarify neuromyths theoretically and empirically. A phenomenon that can be observed at the meta-level is that little work educating people in practice has been conducted despite the existence of numerous theoretical descriptions and studies on neuromyths. Positive examples of providing information about neuromyths include Web-based approaches (e.g., Organisation for Economic Co-operation and Development [OECD], 2015; Rousseau, 2020) and popular science books (e.g., Lilienfeld et al., 2010; Jarrett, 2014; Beck, 2016; Tokuhamma-Espinosa, 2018). However, these learning offerings do not apply recent research findings demonstrating the strong, long-term effectiveness of constructivist refutational intervention approaches (e.g., Grospietsch and Mayer, 2018; 2021b). Since (pre-service) teachers primarily rely upon TV, the Internet and popular science magazines to read up on neurodidactics (Rato et al., 2013; Ferrero et al., 2016), there is a need not only for easily accessible, effective educational material clarifying neuromyths, but also for scientifically rooted alternatives to bring research results from the young, vibrant disciplines of *educational neuroscience*, *neuroeducation* and *Mind, Brain, and Education Science (MBE)* into the classroom rather than

neuromyths. Grospietsch (2021) translates Grospietsch's, (2019) initial work on a more comprehensive conceptualization of neurodidactics into the language of teachers. This conceptualization is based on knowledge from three disciplines: neuroscience, education and cognitive psychology. The corresponding instructional models demonstrate that psychological models (e.g., multi-storage model of memory, learning strategies theory, the process model of memory formation) can serve as starting points for neuroscientific explanations and foundations for educational conclusions. In a more narrow sense, they function as a bridge between the three disciplines. Grospietsch and Mayer (2020) report based on their research experience that the quality of learning offerings on neuromyths can also be improved through collaboration among the three disciplines.

Taking a meta-perspective view of the theoretical state of research, continued critical attention needs to be paid to the increasing trend of distinguishing between *neuromyths* and *psychological myths* (e.g., McCarthy and Frantz, 2016; Menz et al., 2020). This approach is certainly justified on a theoretical level, since some myths can be better refuted with neuroscientific arguments and others with psychological arguments. However, at least for the subtopic of *learning and memory*, research results by Grospietsch and Mayer (2021a) demonstrate that pre-service teachers apply knowledge from both domains to make fallacious arguments regarding the seven investigated neuromyths. Thus, at this level, the distinction between neuromyths and psychological myths is unsustainable and also not useful for the development of intervention approaches. At a time in which disciplines such as *educational neuroscience*, *neuroeducation* and *Mind, Brain, and Education Science (MBE)* are paving the way for a growing number of interdisciplinary research projects and results, distinguishing between *neuromyths* and *psychological myths* is conceptually questionable. Added to this is the fact the relations among studies are not adequately referenced in the research discourse, even though sometimes the same myths are being investigated. Studies on psychological myths (e.g., Menz et al., 2021a; Menz et al., 2021b), in particular, more strongly see scientific myths as a specific kind of misconceptions and deliver valuable insights on interventional approaches that could advance research on neuromyths. Our pragmatic recommendation would be to begin speaking of neuromyths on *psychological subtopics* or similar, analogously to neuromyths on the subtopic of *learning and memory*, in order to productively bring together not only different disciplines, but also two diverging lines of research, in the future.

## AUTHOR CONTRIBUTIONS

FG drafted the manuscript. IL provided critical revisions. Both authors approved the final version of the manuscript for submission.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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