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"Neuro-educational Approaches": Optimizing Classroom Teaching with Neuroscience Insights

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Abstract

Although many teachers base their pedagogies on neuromyths, there is limited information on how to successfully integrate modern neuroscience discoveries into education. In this research, we used a technique for teacher training known as a "learning study" to look at how teachers picked up the skills necessary to incorporate neuroscience into their lessons. As part of their study in the classroom, the teachers worked together to develop, implement, and assess classes with a neuroscience theme. The study's theoretical framework was derived from theories of brain plasticity, such as the hierarchical relational binding theory, the memory, learning, attention, and awareness models of neural networks. We used a number of data sources and phenomenographic techniques to create categories that represented the instructors' involvement with neuroscience. The results showed how crucial a role analogy played in instructors' application and understanding of neuroscience material. We used the analogies of the "rose," "butcher on the bus," "deepening the trenches," and "walking the pathway" to show how teachers' newfound knowledge led to changes in their pedagogical practices, including a move away from more traditional, lecture-based methods and toward those that make greater use of multiple modalities in instruction and the creation of more cohesive learning experiences for their students. Findings point to how neuroscience may help instructors create theoretical consistency in their conceptions of teaching and learning. Discussed are the implications.

Keywords: Neuroscience; classroom teaching; primary education; teachers

Introduction

Educators and researchers alike are starting to pay greater attention to the field of educational neuroscience as it shows promise as a tool for improving theory-informed instruction and PD for educators. Recent discoveries, made possible by advancements in technology, are posing serious problems for established ideas of how the brain processes and stores information in preparation for learning. In the 1990s, educators, academics, and businesspeople focused heavily on bringing neuroscience to education in an effort to enhance both teaching and learning. Despite widespread recognition in the current educational neuroscience literature, early attempts to link brain research to classroom teaching were mostly hypothetical and did not address the barriers inherent in integrating neuroscience and education (Grospietsch & Lins, 2021; Weni Nelmira et al., 2022). The absence of a clear research paradigm and robust philosophical underpinnings in the early stages of educational neuroscience contributed to the proliferation of widely held neuromyths (Shihabudheen & Pillai, 2018). Neuromyths are commonly believed but misguided notions of how the brain functions.

Despite the fact that neuromyths have been exposed in the present academic literature, instructional methods based on these myths are still frequently employed in schools and starting teacher education programs (Conn et al., 2022). The fact that these myths are spread across society through widely held yet false beliefs about how the brain functions is similarly concerning. Academics have worked hard to dispel myths and legitimize educational neuroscience, yet many people remain dubious about the potential of brain research to affect education (Thomas et al., 2019). The emerging field of educational neuroscience centers debate on the exchange of information, concepts, and research findings between neuroscience and education (Nuryana & Fauzi, 2020). It has been noticed that it is challenging to connect the two (van Dijk & Lane, 2020), and this difficulty is partly related to instructors' lack of training. Due to difficulties in explaining neuroscience findings to instructors and difficulties in comprehending how neuroscience and education vary, there is a knowledge gap that leads to the persistence of neuromyths (Grospietsch & Lins, 2021). It also leads to the sparse use of neuroscience to teacher professional development. There seems to be a lack of empirical research on the complexities of combining neuroscience and education, as well as the application of neuroscience concepts in traditional classroom settings (c.f. Tan & Amiel, 2022, for examples of teacher professional development workshops in neuroscience).

Our research, which presents an instance of teacher professional development, focuses on instructors discovering how to integrate neuroscience knowledge into lesson plans. The research bridges the gap between the aforementioned three bodies of knowledge (research, literature, and classroom practice). The research is undertaken with a cohort of elementary school educators utilizing a professional development (PD) method known as the learning study (LS) In contrast to traditional forms of teacher professional development (PD), we utilized the LS to inspire teams of educators to design, implement, and evaluate long-term neuroscience-framed activities as part of their own classroom research. The Learning System (LS) was recently proposed as a useful framework for teacher neuroscience professional development by Wilcox et al. (2021). The authors argued that the LS could help educators become more knowledgeable about neuroscience, apply theories from the field to classroom settings, and determine whether or not the strategies are actually helping students learn.

This study's primary goal is to educate instructors to specific neuroscience knowledge that, in our opinion, may enhance present classroom education. The second case study illustrates how instructors might utilize neuroscience knowledge by engaging in LS dialogue that is theoretically oriented. The study differs from prior types of brain-based research in that it focuses on the instructors' experiences interacting with neuroscience knowledge rather on learning deficiencies like reading difficulties (Bailey et al., 2018). Instead, we focused on how education may be improved by using knowledge from brain research, particularly that related to neural plasticity.

The underlying question that will be investigated is: *What did five primary school teachers learn when they took part in a case of LS using a neuroscience framework?* The focus of this work is on two guiding questions, which are as follows: *What did the educators' experiences learning about neuroscience throughout the LS look like from their perspectives? What elements of neuroscience were used by the instructors to shape their instruction and student learning during the LS?*

Review of the literature on neurology and instructional strategies

The incorporation of neuroscientific perspectives into the area of education may be traced back to the methodological and conceptual groundwork laid by cognitive science in the 1980s and 1990s (Gage, 2019). However, there are two main ways that recent neuroscience discoveries diverge from prior literature. First, investigations conducted nowadays may be seen as being more academically rigorous since they take into account how neurological processes function in the context of well-defined cognitive models. Early cognitive neuroscience relied heavily on data and was described as "messy" (Girgis et al., 2018; Eti Hadiati et al., 2022), and it often lacked concise theoretical frameworks that enabled for significant links to be made between brain activity and cognitive function. Neuroscientists have been driven to be more explicit in their connections between brain function and learning as a result of obstacles posed by the burgeoning field of educational neuroscience (van Dijk & Lane, 2020). Second, more in-depth and precise insights into brain activity and learning have been made possible by new and improved imaging methods, e.g., oscillatory temporal sampling. Detailing the differences would go beyond the scope of the paper's thesis, but suffice it to say that empirical neuroscience research may help to advance both cognitive sciences and teaching methods (Vaughn et al. 2020), creating new opportunities for teacher professional development. We looked at three different lines of research in neuroscience concerning neuronal plasticity, or the capacity of the brain to change over time. We concentrated on these components because they provide the theoretical support needed to generate changes in instructors' perceptions of teaching and learning. According to Tan & Amiel (2022), this ontological transformation in teachers' perspectives on human learning has the power to radically alter how educators approach lesson planning and curriculum development.

The theory of learning based on neural networks

Simply viewing an image of a rose is not as efficient a teaching tool as actually touching a real rose (Poulou et al., 2019). A well acknowledged theory of knowledge formation, the neural network hypothesis of learning and memory is based on the study of Canadian psychologist Donald Hebb. Hebb put forth a key explanation for how synaptic plasticity—the capacity of brain cells to modify their connections over time—works. According to the notion, the mental representation also known as memory of an object or concept is kept in a greatly distributed network of linked brain cells, or the neural network. Repeated exposure to cognitive or sensory stimuli may improve brain connections, according to scientific research (Tanil & Yong, 2020). (Tanil & Yong, 2020). In contrast, connections deteriorate if they are dormant for a long time, making it more difficult to access the data. The ability of the brain to make, maintain, and break connections is assumed to underpin the cognitive processes of memory essential for learning. According to the theory, when a student interacts with a learning object for the first time, a distinct network of brain cells that carry all of the sensory data connected to the item are activated (Poulou et al., 2019). Revisiting the learning item, giving it emotional significance, and/or using additional senses all aid in improving memory retention by strengthening the connections between brain cells. A robust mental picture of the learning object will be created by a strong network of tightly linked brain cells. This representation may then be subsequently remembered, altered, and expanded by more learning events. This means that education should focus on providing pupils with a wide range of sensory experiences that have a real, tangible effect on their brains and their worldviews.

Hierarchical relational binding theory (hRBT)

The likelihood of remembering the learned thing increases with the strength of the neural connections between brain cells. The theory proposes that our mental representations of the items we use for learning are composed of smaller pieces of data that are processed and stored elsewhere in the brain. When a student attempts to remember a learning item, they are put back together (reassembly). A mental image of a rose, for instance, can contain details about its size, color, texture, scent, shape, and emotional connotations. According to hRBT, the individual brain areas responsible for first processing the many sensory data points that make up the mental picture of a rose are independently retained. The hippocampus is involved in the consolidation of knowledge when the student tries to replicate the concept of a rose (Poulou et al., 2019; Abdul-Hussain et al., 2022). There is a positive correlation between the density of synapses between brain cells and the success of long-term memory storage. Strong recall is the opposite of poor recall, in which the learner just has a vague idea of knowing the material. These viewpoints might result in at least two practical uses in education. The first benefit of revisiting ideas is that it helps to strengthen the neural connections between brain cells, which enhances memory. Second, it is urged to associate the topics under consideration with feelings.

Attentiveness and consciousness: familiarity, novelty and emotions

The brain sorts the data it receives and selects which ones to focus on. Numerous studies have hinted at the significance of emotions in aiding the brain's process of prioritizing information that finally comes into the learner's focus of attention. The amygdala, a part of the brain responsible for processing emotions, is activated by both happy and negative emotions. Additionally, the storage of memories with emotional connotations occurs in this area of the brain (Laudenbach et al. 2019; Pakorn Akkakanjanasupar et al., 2022). Positive feelings have a positive impact on a learner's memory recall, engagement, and focus, all of which have implications in the classroom. Another element that impacts whether attention is focused on a desired learning item is novelty (Kucker et al., 2018; A Akmam et al., 2022). Novelty is the element of surprise connected to an unforeseen occurrence or an occurrence that takes place out of context. The attention-related feature of novelty is counterintuitive in certain ways. New knowledge needs to be original, i.e., include a distinct dimension not before seen. To link to an already-existing network in the brain for that specific notion, instructional assignments must be placed at a level that is suitable for students' experiences. Similar to this, it is crucial to elicit past knowledge from students while introducing new ideas, which highlights the need of probing for knowledge. Before integrating these separate pieces of information together, it is important to increase students' familiarity with them. It is essential to expose students to the material that would make up the learning object in a systematic way beforehand.

Methodology

Research design and Participants

Participants in the LS were five instructors from the same independent school teaching grades 1-6. In contrast to most LS, the instructors were from various grade levels, and they were separated into sub-groups of higher and lower grade levels to make lesson preparation easier see Table 1, pseudonyms used. All of the instructors are certified educators who have a minimum of a Bachelor's degree. The study's participants were chosen based on their availability as part of the school's professional development program. Participant and ethical approval were both obtained. By providing a location for the weekly sessions, catering lunches, and making arrangements for replacement instructors to cover the participating instructors when required, the school administration supported the project.

Table 1. Teaching experiences and grade levels of participating instructors.

Names (pseudonyms)	**Sub-Group**	**The number of years spent teaching each grade level (years)**	**Total Number of Years Spent Teaching in General (years)**
Angel	Lower grade level	Grade 1 with 2 years of teaching	16 (preschool)
Daine	team	Grade 1 with 4 years of teaching	14
Rica		Grade 1 with 2 years of teaching	4
Ina	Higher grade level	Grade 4 with 1 year of teaching	6
Nate	team	Grade 6 with 1 year of teaching	3

Study structure for learning

The teacher PD strategy was determined to be the LS framework. Our LS is built on the idea that teachers may learn by interacting with educational ideas and viewpoints, and that information can then be used to think critically and theorize about their teaching (Halliday et al., 2019). This will help teachers become more knowledgeable, enhance their teaching techniques, and help students learn. As they collaborate to plan, deliver, and evaluate theory-framed classes, instructors have opportunity to interact with new ideas because to LS. Educators construct and integrate theoretical, empirical, and content-based knowledge to provide holistic views of the relationships between theory and practice (Ivars et al., 2018; Sonya Nelson et al., 2022). Teacher learning is bolstered by classroom-based research initiatives in which educators apply theoretical perspectives to a deeper understanding of their own teaching practices and the relationships between pedagogical decisions and student achievement.

Our LS includes the stages below; for further information, see Figure 1. Our LS was based on the LS framework created by Ivars et al. (2018).

(1) Theory investigation, including a presentation and discussion of relevant neuroscience material;

(2) Collaborative lesson planning, in which instructors combined the teaching of English with neurobiology;

(3) Research conducted in classrooms by instructors, who then had group members watch while they taught classes using a neuroscience framework. Team members used their reflections to enhance following classes they delivered;

(4) Post-lesson conferences where instructors reviewed and reflected on the lessons and neurobiology; repeated cycles of teaching-reflection-feedback;

(5) Sharing of educational experiences, including a neuroscience workshop for teachers in the province that the instructors assisted in facilitating.

(1) The researchers participated in the project as researchers as well as LS facilitators and teachers' learning advocates. (2) The researchers did not specify the method of instruction for the classes. The fact that the researchers weren't seeking for any particular pedagogies is also made clear to the instructors. (3) Team members modify classes via iterative teaching cycles as a result of their observations and reflections throughout lessons. (4) Teachers spoke about how they were going to incorporate neuroscience into their lessons, what they taught, and how much their students learned.

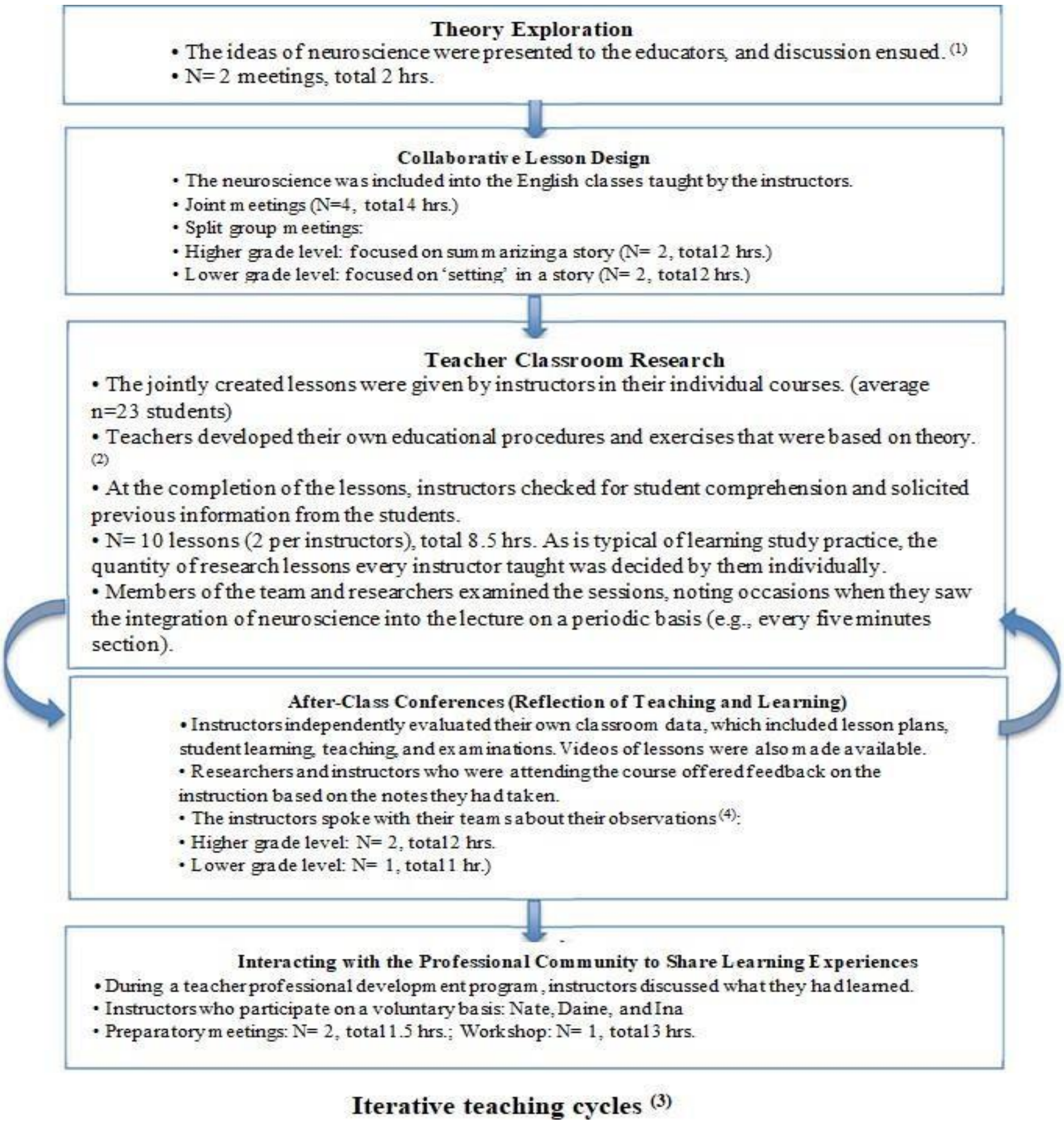

Figure 1. Implemented learning study cycle.

Theoretical framework

In order to emphasize the hRBT, neural network theory for memory and learning, and attention and awareness, we organized the instructors' LS discourse and analysis as shown in Table 2. We also used phenomenographic perspectives to analyze the data, which define learning as the capacity to experience a phenomenon of interest in a more sophisticated or complicated manner than one would have before. Learning was conceived as the development of ever-more-complex pedagogical experiences, and the work presented here centered on teachers' interactions with particular neuroscience material. The experiences could cause instructors to rethink how they approach teaching and learning or alter their pedagogical methods.

Table 2. The learning research examined topics related to neuroscience.

Content related to neuroscience	Key ideas	Ideas explored
Learning and memory neural network based on the neural hypothesis	Being made aware of the notion that learning involves the construction and reinforcement of brain networks	● Synaptic plasticity and how it affects how the brain stores events as memories.
		● How expanding neuronal connections may enhance notions (Tanil & Yong, 2020).
		● The Visual-Auditory-Kinesthetic (VAK) paradigm of education as compared to the multimodal approach to teaching and learning (Grospietsch & Lins, 2021).
Hierarchical relational binding theory (hRBT))	A focus on the many connections that connect the networks of brain cells linked to a particular notion, emphasizing the need of review, repetition, and reinforcement in creating strong networks (Idrissi et al., 2020).	● Each of the network's potential directions is stored in its own dedicated location in the brain's original processing hub.
		● The brain's (hippocampus) integration of the data (event characteristics) recreates the notion, which is then remembered.
		● In order to learn, the learner might adjust or adapt the networks in light of new knowledge or experiences.
		● Between familiarity and complete remembrance, there is a distinction.
Attention and Awareness	The significance of providing the necessary conditions for learning, such as awareness of students' pre-existing networks related to the target idea, effective scaffolding, and appropriate levels of concept complexity (Tanil & Yong, 2020).	● What knowledge is significant and worthwhile preserving is decided by the brain.
		● The brain is a device that recognizes patterns (Tanil & Yong, 2020).
		● The significance of establishing recognisable patterns.
		● Keeping the right balance between novelty and familiarity (Idrissi et al., 2020).

		● Emotions' function.
		● USE of pre-lesson probesand post-lesson comprehension tests (Idrissi et al., 2020).
		● Importance of methodically presenting the intended concept's defining characteristics (event characteristics) beforehand (Idrissi et al., 2020).
		● A connection to lack of attention among students.

Analysis and data sources

To document the instructor experiences, we used phenomenographic perspectives. We primarily focused on the instructors' own narratives of their LS experiences in line with the methodology, and the analyses' conclusions included categories of description that indicated different teaching strategies the teachers discovered. Individual teachers' thorough and open semi-structured interviews served as the primary data source, with phenomenography taking on a second order viewpoint (Barattucci & Bocciolesi, 2018; Muthmainnah et al., 2022). Every interview lasted around one hour, and there were three total. The pre-study interviews (n = 5) probed the teachers' pedagogical and pedagogical stances before to the LS, whereas the post-study interviews (n = 5) probed same stances following the LS. The comparison illuminated the teachers' LS-based learning processes. One year after the study was finished, three teachers were questioned to see whether and how they used neuroscience beyond the research, what components of neuroscience they applied, and thus referred to features they failed to apply (Daine, Ina and Nate).

The interviews were verbatim transcribed, and a variety of data sources were triangulated with it, such as Fieldnotes, classroom resources, research course videos, training materials, meeting recordings and notes, and student materials like tasks that are offered voluntarily. These provided the relevant case information and the context for locating the professors' statements (Ivars et al., 2018; Pakorn Akkakanjanasupar et al, 2022). For instance, the interviewees' descriptions of the instructors' teaching and learning experiences were contrasted with the class observation notes and video recordings. In order to find various parts of instructors learning experiences that took place during the conversation, we utilized the data sources to build detailed descriptions of the LS environment.

Using the phenomenographic approach of (Ivars et al., 2018), we grouped the teachers' experiences with neuroscience into three distinct categories, each of which describes a distinct set of events that were central to a particular way that the teachers as a whole encountered the learning process. To avoid evaluating the instructors' experiences, we deviated from phenomenography and did not organize the categories. In order to create, test, and improve categories, analysis comprised marking and compiling pertinent portions of the data set (Ivars et al., 2018). For the purposes of this article, we focused on the analogies the instructors employed since they stood out as a key component of how they discussed how neuroscience has affected their learning and pedagogical decision-making processes. According to studies, analogies help students learn by making new or abstract ideas more real, approachable, and retrievable (Körhasan & Hdr, 2019, Kim et al., 2018, Kim & Loewenstein, 2021). We started the analysis after the LS was finished and gave the process enough time to complete itself in order to prevent premature building of theoretical structures or interpretations. To make our findings more credible, we used triangulation techniques. By routinely comparing, exposing individual studies to examination, and testing ideas together, we were able to assure dependability. The results became the subject of much debate. These procedures helped the data set's overall interpretation to emerge. As part of a peer debriefing process, a PhD student with expertise in neuroscience, learning studies, and qualitative research assessed our data analysis, "findings," and drafts of our article.

Findings and Discussion

1. Increasing awareness of how knowledge is created: the "rose" analogy

This group is distinguished by the instructors' use of theoretical neuroscience to broaden their comprehension of how students create their knowledge and then to put that understanding into practice. The neural network concept and how people may add to, strengthen, and remove connections between brain cells were first introduced using a "rose" analogy, which was modified from Poulou et al. (2019) for example, synaptic plasticity. As a result, the instructors investigated strategies for encouraging strong mental representations of learning items, including the development of several brain pathways and modalities that include a variety of senses, abilities, and presentational styles. The findings suggest that the rose analogy helped the teachers retain and apply a fundamental notion to understand how youngsters acquire information. This is seen in the example that follows, in which Nate utilized the analogy to explain how information is coded, processed, and stored by the senses, stored in multiple locations, and recalled via the hippocampus. Nate furthered the parallel by drawing a comparison between weak and strong connections.

(1) Interviewer: So, could you explain to us how a child acquires knowledge?

Nate: The concept of the four or five senses that make up our body processing information For efficiency, the sensory data is stored in many places. The rose served as our illustration of how something coming back to you allows you to add to the sensory information you already have. For instance, someone could taste the rose and then notice how it looks. The hippocampus then brings all of this information back together after it has been stored in separate parts of the brain. Then, all of your senses begin to function. Depending on how they are joined together and how often they are accessed, the connections made might be stronger or weaker.

Although not all of the team's instructors were as fluent in their explanation of the rose analogy's applicability to classroom instruction as Nate was, they were, for the most part, able to understand it. For instance, Ina discussed in the interview how she related the analogy of the rose to how various cerebral connections, or "multiple pathways," are linked to a thought. Then, in the research classes, we saw how she encouraged the students to investigate several interpretations of a single term by putting this understanding into practice. In her own words, her pedagogy was:

(2) Ina: I'm thinking about the rose example you gave, where several routes are made for a single word. That caught my attention and got me thinking about words, in my opinion. I used breaks and pauses to clarify things with the kids, or I offered them the chance to investigate—suppose let's it was just one word—different interpretations of that term. To put them in various relevant settings is what has remained with me.

The neural network hypothesis has the potential to broaden instructors' perspectives on learning, and chances to teach and reflect on the research lessons have been shown to improve the ways teachers have implemented the ideas. Like Ina, the instructors understood the value of developing many cerebral pathways, which, in concrete terms, may include giving pupils a variety of entry points to the meanings of a learning item. Older learning models that differentiated pupils based on their learning styles were not used in this method of teaching and learning. The participating teachers were taken aback by the neuromyths, and they provided examples of teachers who are still firmly rooted in outdated notions of learning styles, which is problematic because of how teaching with the VAK model has been made more difficult by advances in our understanding of how the brain works (Grospietsch & Lins, 2021).

Daine, in one of the LS sessions, brought up the fact that her gym instructor was using the VAK paradigm and emphasized the prevalence of neuromyths outside of the classroom. She emphasized the necessity to notify instructors that "the VAK model is outmoded" during the professional development program we jointly executed with the teachers fieldnotes. This demonstrates the value she placed on knowing neurology. She also said that dispelling the neuromyth was one of the most beneficial things she learned from the research in the post-study interview that was conducted afterwards. In conclusion, the instructors explained the neuroscience concepts presented in the rose analogy and modified their pedagogies to reflect this new knowledge. According to Kim et al. (2018) and Kim & Loewenstein (2021), the comparison seems to make otherwise complex and abstract scientific studies on the brain more understandable for instructors while also enabling them to address neuromyths that are often spread in classrooms and society at large. The instructors eventually realized how crucial it was to provide pupils a range of experiences that gradually deepened and reinforced their comprehension of the learning item.

2. Combining the metaphors of "the rose" and "the butcher on the bus" to deepen instructional methods

We used the "butcher on the bus" example during the LS sessions to illustrate a case of familiarity when a person was unable to properly recollect where he or she had previously seen the butcher. In other words, it distinguishes between remembrance (strong recall) and familiarity (vague recall), which is attributable to the varied ways that the brain processes information. Through the debate, it became clear how crucial it is to repeat, review, and revise lessons as well as to design cohesive learning experiences. These are all effective teaching strategies, but they are not often implemented consistently in actual classroom settings.

The "butcher on the bus" comparison, like the rose metaphor, connected the teachers' old ways of thinking about education to their more modern perspectives. It's interesting to see how often the instructors combined the ideas from the rose with those from the "butcher on the bus" analogy. In other words, the instructors merged educational concepts from the neural network theory with those from the hBRT; this is a defining characteristic of this category. The portion of Excerpt 1 depicting knowledge generation by students using the rose analogy was inspired by neural network theory, whereas the section depicting the hippocampus and information retrieval where "information comes back together" was inspired by the hRBT. It is worth noting that the two theories/hypotheses were produced using distinct scientific research approaches and were argued in separate sessions. Nate, like some of the other academics (Daine and Ina), apparently merged the two by tying the parallels, with an emphasis on the relevance of extending neural network hypothesis and reinforcing (hRBT) neural networks for a particular idea. This is consistent with Körhasan and Hdr's (2019) observation that the strength of analogies is in giving students the opportunity to build their own understandings. In this case, the teachers' meaning-making processes include linking the parallels, which recasts the commonplace experiences of a rose and a chance encounter on the bus in new light (Kim et al., 2018).

We also saw that Nate blended the analogies to help him design his class. In addition to emphasizing multisensory learning experiences derived from the "rose" analogy, he placed a strong focus on exposing pupils to the data that made up the learning object in advance, which is known as event features in neuroscience. Pre-exposure ensures that students can meaningfully apply the knowledge to new content, much like adding new event features to pre-existing brain connections (Idrissi et al., 2020). These findings are consistent with the hRBT. On the team's lesson planner, Nate wrote "butcher on bus" next to the pre-exposure column to emphasize the importance of this step in the process of preparing the lesson. To further his explanation to Ina, he referred to the concept of a "brain network," which holds that when we do anything for the first time, we are really retracing our steps along a path we have already traveled video-recording of LS meeting. When we looked into the line of inquiry concerning the teachers' incorporation of the neuroscience theories and the analogies, we found that the teachers frequently used the rose analogy in relation to how children learn, and that the "butcher on the bus" shaped the practical implications for teaching. Two instances of this are Nate's usage of the "butcher on the bus" and the "rose analogy" to explain how children learn as described above. Other times, like in Daine's example below, when she was attempting to illustrate how children may develop solid conceptions by creating deep routes, the parallels and theoretical viewpoints were not differentiated:

(3) Daine: These networks and the paths are being built by you. The more the rose was experienced, using all five senses, the more complicated the pathways got. Your comprehension of anything improves as the pathways get deeper, kind of building up your knowledge of what something is.

Similarly, Ina described how she included the "butcher on the bus" into her study presentations. She tried out letting students use a number of methods including sketching and writing to summarize a video animation (see Excerpt 4). Ina said, "I still like the notion of offering people alternatives to model their summary. Isn't it better to let them choose?" during the planning stage. (LS meeting video recording) Ina gave students a variety of resources to learn with and to exhibit learning, which was consistent with her priority of "students being able to show me how they have learned in their own words" (pre-study interview). The teaching technique may be seen as both expanding and strengthening brain networks when framed in terms of theoretical neuroscience.

(4) Ina: 'We spoke about the "butcher on the bus" scenario, when you recognize and see the individual but are unsure of their whereabouts. I believe that sometimes they show me, write it down, or draw anything related to location or tale so that they may learn what that term means. They can demonstrate things to me in a variety of ways, and ideally they will have the skills necessary to convey that information in writing.

Overall, it felt like teachers were shifting their pedagogical techniques to place greater emphasis on creating constructivist-framed learning opportunities and encouraging students to make new brain connections. The instructors realized that they needed to move away from more traditional didactic methods of instruction, and they embraced a wide range of pedagogical approaches to give students novel opportunities to interact with and demonstrate competence with key concepts, thereby broadening their neural networks' capacity to hold and process those ideas. For instance, the Grade 1 teachers used the research lessons to have their kids build a gingerbread home so that they could experience a setting inside a tale as opposed to being taught what a setting is. In a similar manner, Ina gave her Grade 4 pupils a chance to practice summarizing by having them watch a little animation movie, take notes, and then explain the plot without being told what a summary is interview excerpt. By assessing the usefulness of print and online materials, Nate had his sixth-grade pupils investigate the essential components of a summary on their own. The instructors showed a greater appreciation for the implementation of novel educational techniques that were motivated by neuroscience as they reflected on the research lessons, student learning recorded via different assignments, and the comments given by colleagues. For instance, Ina discussed with the team at the post-lesson conference the uniqueness and potency of employing video animations to enhance learning about summaries for the first time for the particular learning object.

(5) Ina: We did not explain to them what a summary is. It was thus incredibly intriguing to offer them that example or experience and to clearly see who is able to apply their knowledge at that precise time to create that summary. Then to see people for whom the building was absolutely necessary but was absent.

Once again, we saw instructors shifting in the direction of a constructivist teaching philosophy in which they offered experiences that revealed and enhanced students' comprehension of the learning object. Teachers also engaged in context-appropriate activities with the LBO in order to determine which features of the LBO deserved the most emphasis in the classroom. That is to say, a central feature of constructivist approaches to education is the incorporation of formative assessment into class time.

3. Increasing knowledge of theoretical neuroscience via the use of the analogies of "deepening the trenches" and "following the trail" created by instructors

In order to better comprehend theoretical neuroscience, the instructors in this category developed their own parallels. As a result, they utilized what they learned to their teaching practices both during and after the LS. In order to demonstrate how neural networks may be strengthened, instructors often used the phrases "deepening the trenches" and "following the trail" during LS sessions. The instructors said that the brain network theory may "deepen the trenches" by developing various learning pathways and providing students with a variety of sensory experiences. The hBRT suggests that strengthening neural networks may be achieved in part by encouraging frequent "walking the route," which reflects the importance of repeated learning experiences. To make sense of the neurobiological evidence that reveals what and how students learned, teachers construct parallels, as stated by Körhasan & Hdr (2019) and Kim et al. (2018). The importance of the fabricated analogies in elaborating the similarities between the "rose" and the "butcher on the bus" and the underlying neuroscience principles cannot be overstated.

During the LS sessions, the educators gained a deeper understanding of attention, awareness, and the brain's process of categorizing and prioritizing data. A teaching resources and videos of LS sessions document our more pragmatic approach to supporting instructors in their struggles with subjects related to attention and awareness. We pushed the instructors to think about the value of methodically teaching event aspects, or the pieces of knowledge making up the specific notion, in advance (Idrissi et al., 2020). We also spoke about the need of getting enough prior exposure to the event's elements and attempting to strike a balance between familiarity and novelty. Again, our study revealed that constructivist-oriented teaching methods were reinforced. The instructors gained expertise on how to detect, strengthen, and expand existing connections between brain cells by using different approaches to probe students' past knowledge such as "deepening the trenches" and "walking the trail". In this context, Daine emphasized the significance of developing and strengthening brain connections, saying that neuroscience "gave the language required to describe learning" (interview clip).

Similar to this, instructors commonly compared the teaching method of exploring students' past experiences to "deepening the trenches," wherein doing so allowed teachers decide which event characteristics to emphasize and expose students to beforehand. Angel highlighted that "You can't simply leap into establishing targeted idea," as did a number of the other instructors. Giving them certain abilities and using their existing knowledge in order to apply it in a situation is crucial (interview excerpt). Even while it is common knowledge of what makes for excellent teaching to elicit students' previous understandings, neuroscience gave the instructors fresh views on its significance to student learning: as 'deepening the trenches' by connecting and expanding brain connections. In Angel's research lesson, students in Grade 1 completed a worksheet on the tale of "Jack and the Beanstalk" as part of the probing, and as part of the previewing of the idea of "setting," kids built gingerbread houses. She clarified in the interview how she would have ignored these details anyway, just like the other Grade 1 teachers did:

(5) Angel: I probably would have stated, "Okay, here is the setting," in the past. There wouldn't have been a preview or any research on my part. I thought it was great since it gave me insight into their level of understanding and what I could do to assist them grasp the concept of a setting. I'm seeing that this is something I do while performing arithmetic. I'll inquire as to what they understand by addition. or what they believe subtracting to be. When do they anticipate using it. These abilities are being used by me a little bit more than in the past.

Like the other instructors, Angel believed that soliciting information from students and preparing them for learning were abilities that could be used outside of the context of the LS, like as in math sessions. "Checks for comprehension" were also used by the instructors as a sort of informal evaluation. Despite assessments often being created at the end rather than the beginning of lesson planning and instruction, the teachers explained how the LS discussions about "deepening the trenches" influenced the ways in which they made sure that the event features of the targeted concept they identified were consistent with what was being assessed (Nate, interview).

The teachers also linked the idea of recurrence with the value of developing consistency in their methods of course design, delivery, and evaluation. This connection was made through analogies they developed to highlight the strengthening of brain connections. This was accomplished through synchronized teaching strategies such probes, pre-exposure getting students ready to acquire the targeted topics, in-class instruction, and "checks for comprehension." The instructors noted in the post-study interviews that they continued to use this practical use of neuroscience knowledge as a teaching concept. To provide just one example, Ina shared her neuroscience-framed insights with Grade 4 teachers who did not take part in the research, by helping them construct curricular units and teaching utilizing the notion of coherence as is informed by neurobiology. The emphasis is shifting from teaching students what they need to know to designing engaging and relevant learning experiences for them. Nate and the grade-level teams of teachers who work with students in lower grades have been informed of these goals. This satisfies a crucial objective of the LS by allowing instructors to apply effective teaching techniques learned in the LS to their regular lessons and to share what they've learned with a larger professional community.

Further reflection

In order to isolate the lessons, we learned from the research, we thought back on the created categories that represented the experiences of the instructors.

1. Instructors were able to understand key concepts in neuroscience by using analogies

The lecturers made a connection between cognitive processes and brain functions. The analogies that the instructors created helped to solidify their understandings of the material related to neuroscience, which were then put to the test and improved throughout the research courses. With support from the positive outcomes of analogies that have already been shown (Körhasan & Hdr, 2019, Kim et al., 2018), future research and professional development programs should study further parallels that would make abstract topics in neuroscience more intelligible to instructors.

2. The instructors' use of metaphors and neuroscience material could have been a result of the way we presented the information.

To aid instructors in comprehending the neuroscience material, we utilized the analogies of the "rose" and "butcher on the bus." The instructors' use of the same comparisons throughout the interviews is expected, but this clearly shows that the analogies were the teachers' way of remembering the neuroscience material. The lecturers' use of analogies in rethinking the results of the neuroscience theories and hypotheses is also crucial. As they synthesized theoretical and research-based knowledge (neuroscience), disciplinary content knowledge, and pedagogical knowledge to create integrated understandings of the relationships between neuroscience and their own pedagogy, the analogies provided a framework for what and how they learned (Körhasan & Hdr, 2019). This kind of educator theorizing, which is a component of professional development for teachers, has been described in a similar way previously; the present study broadens the theoretical discourse that teachers may participate in by include recent neuroscience findings.

To make the neuroscience topic more approachable, we developed a simplified vocabulary, and we observed how the instructors alternated between using it and the scientific jargon. Thus, the hippocampus and amygdala, two brain regions crucial to remembering both positive and negative emotions, were seldom discussed in classes. These concepts were introduced in the readings but were hardly elaborated upon. At this time, it is not obvious if the instructors are actively rejecting this aspect of the neuroscience content or whether their inability to incorporate it in their descriptions is a direct effect of the course corrections we instituted in the discussions. It is consistent with the literature that teachers struggled with the use of hippocampus and amygdala words from the neurosciences, and this is an area that need further investigation. The goal of this work is to increase the availability of neuroscience journal articles for classroom discussion, so allowing students and teachers to delve more deeply into the field's terminology and concepts.

3. Going beyond educating using multisensory methods

The necessity to disprove neuroscience theories like the VAK model was underlined by the professors. The instructors' move away from distinct learning styles is mostly restricted to multi-sensory or -modal types of education, as we have seen via the study classes and interviews. In this context, Angel has discussed the challenges of departing from the VAK model, saying that neuroscience "has affected my thinking a little bit... But it's hard to change my mind because I still consider myself as a visual learner" (interview excerpt). Angel's remarks make reference to the VAK model's widespread use and how instructors' beliefs are firmly rooted in the concepts of learning styles (Grospietsch & Lins, 2021).

Further investigation suggests that the constraints may also be related to the instructors' interpretation of the neuroscience data as it was mediated through the parallels. Nate's depiction of student learning in Excerpt 1 focuses on various sensory inputs, for instance, using the "rose" comparison. Instead of concentrating largely on various sorts of sensory input, a more relevant conceptualization of the theory may shift away from that. Educators would do well to highlight the connection between neural network expansion and the gathering of more pertinent data about the learning object, such as the object's event attributes, in order to drive home the significance of these constituent parts. The color and shape of a rose, for instance, are both features of an event that need vision, although they activate distinct but related brain regions. It's important to us to learn more about this. More people may benefit from this approach to schooling if they learned to think of brain connections as processes rather than as collections of sensory data.

4. Can neuroscience provide something?

Our research indicates that neuroscience has a significant impact on teaching methods, which provides preliminary evidence for its inclusion in teacher professional development programs. First and foremost, there were significant shifts in the instructors' perspectives on how people build knowledge. For instance, in order to provide instructors a clear knowledge of how the brain works, neuroscience rooted their understandings in current scientific research that is backed by cutting-edge technology tools. This builds on prior cognitive science studies that suggested that instructors may not always base their instructional choices on a thorough grasp of how the brain works (Grospietsch & Lins, 2021).

Furthermore, instructors might analyze the connections between teaching, student learning, and their pedagogical choices using the theoretical lenses given by neuroscience ideas. The findings are consistent with literature that advances the idea that instructors' professional work is inextricably linked to theoretical work that involves learning to reflect on one's own teaching practice (Halliday et al., 2019). In this literature, teacher knowledge development is supported by empirical research. It is interesting to note that the instructors were quite clear about how neuroscience guided their teaching, in contrast to the literature which claims that the application of neurobiology to classroom instruction is more intuitive than explicit.

Thirdly, the results showed how altering teachers' perspectives on knowledge building may influence them to adopt constructivist pedagogy, which has implications for teacher professional development. First off, neuroscience may be able to explain discrepancies between what instructors believe to be effective teaching strategies and actual classroom procedures. For instance, instructors may stick to more transmissionist styles of instruction despite the long-standing support for constructivist-framed techniques. Second, classroom teachers were especially led by both classroom and evidence-based (neuroscience) research in their own observations of students' learning experiences, rather than pedagogical approaches. According to learning research, instructors are becoming more sensitive to students' learning (Ivars et al., 2018). The findings increase the body of knowledge on classroom learning possibilities for students. It is a creative and purposeful effort to encourage learning experiences that are aligned with cognitive processing and brain function. Provide educators with a neurophysiological explanation of how students construct knowledge via neuroscience, and they'll be motivated to build lessons that take use of the latest findings in the study of the human brain. This praxis has been found to stimulate the growth of novel, theory-informed methods of instruction that are then used to improve student learning. One word of caution: professors, who are likely to be unfamiliar with theoretical neuroscience, shouldn't go it alone when suggesting real-world applications of brain research. Teachers must collaborate with other specialists in an integrated research community, as many authors have urged, to direct educational practice and avoid misunderstandings and inappropriate uses of neuroscience material (Vaughn et al., 2020).

Conclusion

The small-scale research described in this article involves a thorough examination of how instructors acquired the skills necessary to use recent developments in neuroscience to classroom teaching by involvement in an LS. Teachers learned through improving their understanding of how people generate information and dispelling misconceptions by using analogies to frame student learning and instructional techniques. To better comprehend theoretical neuroscience, the instructors also developed analogies. The instructors shifted away from didactic teaching methods and toward constructivist-framed pedagogy, using neuroscience to design a variety of learning experiences. They created, put into practice, and assessed cogent student learning experiences that were in line with educational ideas derived from neuroscience. The study's depiction of learning refers to instructors' efforts to bridge the theory-practice gap that they regularly encounter in lesson preparation and in connecting teaching and learning. Furthermore, the learning may have continued beyond the instructors' participation in the LS. Future research may include longitudinal methods like as frequent lesson observations, the collection of classroom artifacts, and teacher interviews to determine how teacher learning is sustained after the LS.

Despite being specific to this instance and having little generalizability, the study's findings provide important ideas for both research and teacher education. First of all, analogies serve as a useful tool for instructors to connect neuroscience to teaching and learning; analogies created by researchers and instructors aided teachers in interpreting, fusing, and applying neuroscience. Second, instructors are getting more detailed explanations of how the brain works in relation to learning thanks to modern neuroscience material, which builds on but differs from past brain studies. This information might have a significant impact on pedagogy and pedagogical decision-making. Thirdly, more focus is needed on the stubbornness of the neuromyths that prior applications of brain-based science have helped to sustain. As a PD strategy, the LS gives instructors the chance to challenge these beliefs and provide counterarguments that they may then evaluate and improve in the context of the research sessions. While teacher participants' levels of effectiveness have varied, PD strategies like the LS suggest the possibility for addressing this component of brain-based research that has sparked discussions about its usefulness in the field of education. In light of this, it is worthwhile to investigate how teacher professional development may significantly alter classroom pedagogies and educational philosophies.

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