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A scoping review of research on neuroscience training for teachers

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ABSTRACT

Background: Including neuroscience concepts in teacher training has continued to gain interest. While many studies advocate for this, little is known about currently published research.
Methods: The framework for a scoping review was followed in order to generate a more comprehensive understanding of current research on neuroscience training for teachers. The present study aims to: (1) describe the scope of existing research; (2) summarize findings; and (3) provide recommendations for future inquiry.
Results: Limited studies and methodological issues prevent strong conclusions from being drawn about the impact of this training although most results are promising.
Conclusions: This scoping review provides the first comprehensive summary of the existing research on neuroscience training for teachers and discusses a number of considerations for improving future research in this area.

1. Background

There continues to be great interest in building a bridge between the fields of neuroscience and education [1-3]. This interest is partially evidenced in the establishment of fields dedicated to the construction of this bridge. However, since the emergence of fields such as Educational Neuroscience [3, 4] and Mind, Brain, and Education [5], little has been done to change education in light of our improved understanding of how the brain functions. This includes not introducing teachers to the basic principles of brain function during their training (for the purpose of this review, "training" refers to both initial teacher training and professional development occurring after the completion of initial training). This inaction may, in part, result from the lack of research assessing the impact of neuroscience training for teachers, or confusion over the scope and duration of such training.

1.1. Why do teachers need neuroscience training?

Despite the obvious connection between the brain and learning, the application of findings from neuroscience to education is a contentious topic. Although there is some belief that findings from neuroscience are of limited use to those in the field of education [6, 7], many researchers remain optimistic [1, 3, 4, 8]. While there is a lack of consensus among researchers in education and neuroscience, interest from teachers [9, 10] as well as policy recommendations in the United Kingdom [11] and the United States [12, 13] have continued to support the argument for providing neuroscience training to teachers. To many, the inclusion of neuroscience in teacher training makes perfect sense given the role that teachers play in supporting cognitive development in their students. However, the complexities of applying neuroscience research to education, as well as disagreement over which discipline can best serve as a bridge between these two dramatically different fields [6, 14, 15] have stalled progress in this area of professional development.

While teacher training institutions, and the organizations that accredit those institutions, have not yet widely embraced the idea of providing neuroscience training for teachers, trends in the private sector support that there is tremendous interest in bringing the brain into education. Each year, multiple conferences and professional development opportunities are organized by groups such as Learning & the Brain, claiming to provide neuroscience-related information to improve teaching and learning. Additionally, a number of programmes (e.g., Brain Gym) claim to offer educators cutting edge tools based on findings from neuroscience research. While the purported benefits are attractive to any educator looking to improve their understanding of how the brain learns and their teaching effectiveness, these programmes are often developed based on neuromyths, "a misconception 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." [16].

Teachers' simultaneous interest and lack of training in neuroscience may, in part, support the perpetuation of these neuromyths in the field of education [3, 17, 18]. Evidence supports that these neuromyths (e.g.,

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students learn better when information is presented in their preferred learning style) persist among teachers from a wide of range of cultures and experience levels [19-23]. One unexpected finding in this area comes from the work of Dekker et al. [24] who found that a significant predictor of belief in neuromyths was a teacher's general knowledge about the brain. Surprisingly, teachers who knew more about the brain were more likely to believe myths about the brain. Considering that this study also reported that reading popular science publications, not scientific journals, was a significant predictor of general knowledge about the brain, it is possible this finding represents the impact of poor representation of scientific research by the non-scientific media. The findings of this work underscore the importance of providing scientifically accurate neuroscience information to teachers who may be exposed to myriad misrepresentations of neuroscience research.

While it is reasonable to expect that belief in neuromyths could negatively impact the quality of education provided by a teacher, some suggest the relationship is perhaps more complex. Using a sample of 50 award-winning teachers from the UK, United States, and Australia, Horvath et al. [25] found no difference in the acceptance of 87% of neuromyths from a previously published survey [26]. The non-award-winning teacher sample was taken from previously published studies using the same instrument [19, 23, 24, 26]. While these findings support less of a negative impact of neuromyths on educational outcomes, it is possible that exceptional teachers are less sensitive to the negative effects of believing neuromyths than their non-exceptional colleagues. It is also possible that the various criteria used to determine which teachers receive these awards are not sensitive to outcomes that are influenced by belief in neuromyths.

Neuromyths, while potentially pedagogically harmless, may be cited in support of funding one educational programme over another, resulting in the misallocation of limited resources toward ineffective programmes. Teachers lacking training in neuroscience are unable to evaluate the purported benefits of these programmes and may find themselves advocating for the adoption of ineffective programmes not rooted in actual science. This, in part, forms the foundation of a dominant goal of incorporating neuroscience into teacher training programmes: to reduce the perpetuation of educational neuromyths [27, 28]. Beyond this admirable and relevant goal, it is believed that a deeper understanding of the brain and how it functions will improve the quality of teaching and learning. Approaching learning from a scientific perspective may encourage teachers to think more about the process of learning, leading to pedagogical change and improved educational outcomes [29]. Specifically, neuroscience training is thought to benefit education by increasing the use of pedagogical and didactic strategies associated with active learning [30] or providing teachers with a wider toolkit of resources to support diverse learners with major individual differences [31]. Together, these goals provide sufficient justification for the inclusion of neuroscience in teacher training.

2. Purpose of the present review

The present scoping review aims to identify, retrieve, and summarize literature on neuroscience training for teachers in order to: (1) describe the scope of existing research; (2) summarize research findings; and (3) provide recommendations to guide future inquiry.

3. Methods

3.1. Scoping review methodological framework

In contrast to the narrow focus of systematic reviews [32], the present study utilizes a scoping review procedure. Scoping reviews provide a preliminary assessment of the currently available research on a given topic and aim to identify the nature and extent of research evidence [33]. This decision was made in the interest of gaining a more comprehensive understanding of the current types of evidence available, key concepts, and common research methodologies utilized in this area [34]. The five-stage methodological framework proposed by Arksey and O'Malley [35] guided the conduct of the present scoping review. These stages are: (1) identifying the research question; (2) identifying relevant studies; (3) study selection; (4) charting the data; and (5) collating, summarizing, and reporting the results. Accordingly, the focus of this review will be on the findings of currently published research, not the quality of that research (i.e., critical appraisal). It is also the hope that the results of this scoping review could serve as a precursor for a future systematic review aimed at addressing specific research questions. No protocol for this review was preregistered prior to initiation.

3.2. Research questions

The primary research question of the present scoping review was "what research has been conducted on the effects of neuroscience training for teachers?". The research sub-questions were:

1 What teacher populations have been studied?
2 What training formats have been used?
3 What is the duration and scope of training?
4 What are the current findings on the impact of training?

3.3. Database search strategy

The database Scopus was selected due to the extensive number of journals indexed, and their relevance to the research topic. Different combinations of keywords and Boolean operators were tested in Scopus in order to identify a query string that excluded as many unrelated papers as possible will simultaneously not excluding known relevant papers. Given the observation that teachers may not reliably distinguish between research in neuroscience and other related fields [10] additional non-neuroscience related phrases were included in the searches. The final query string used was: TITLE-ABS-KEY (neuroscience OR [cognitive neuroscience] OR [science of learning]) AND ([pedagogy] OR [teaching]) AND ([teacher education] OR [teacher professional development]) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")). The final database search was conducted on December 31st, 2020.

3.4. Selection of studies

The selection of studies for inclusion followed guidance from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) checklist [36]. The process of study selection is documented in the form of a PRISMA flow diagram [37] presented in Fig. 1. Given the aims of this review, special care was taken to develop inclusion and exclusion criteria that capture only those studies actually assessing the effects of providing teachers with some form of neuroscience training. To be included, a paper must: (1) provide educators (e.g., teachers, administrators, etc.) with a training programme based fully or in part on research from the fields of neuroscience, cognitive neuroscience, or an interdisciplinary field such as science of learning; (2) report the impact of such training on teacher beliefs or behaviours either quantitatively or qualitatively; (3) be a primary study (i.e., not a review); (4) be published in a peer-reviewed journal; (5) be written in English; (6) be published prior to January 1st, 2021; and, (7) have full text available. Studies were first screened through reading of the title and abstract by a single reviewer. Those studies identified as candidates for inclusion went through a full text screening. The article screening and selection process was performed twice in order to assess the reproducibility of results.

3.5. Data extraction

A spreadsheet-based coding template was used in the extraction of

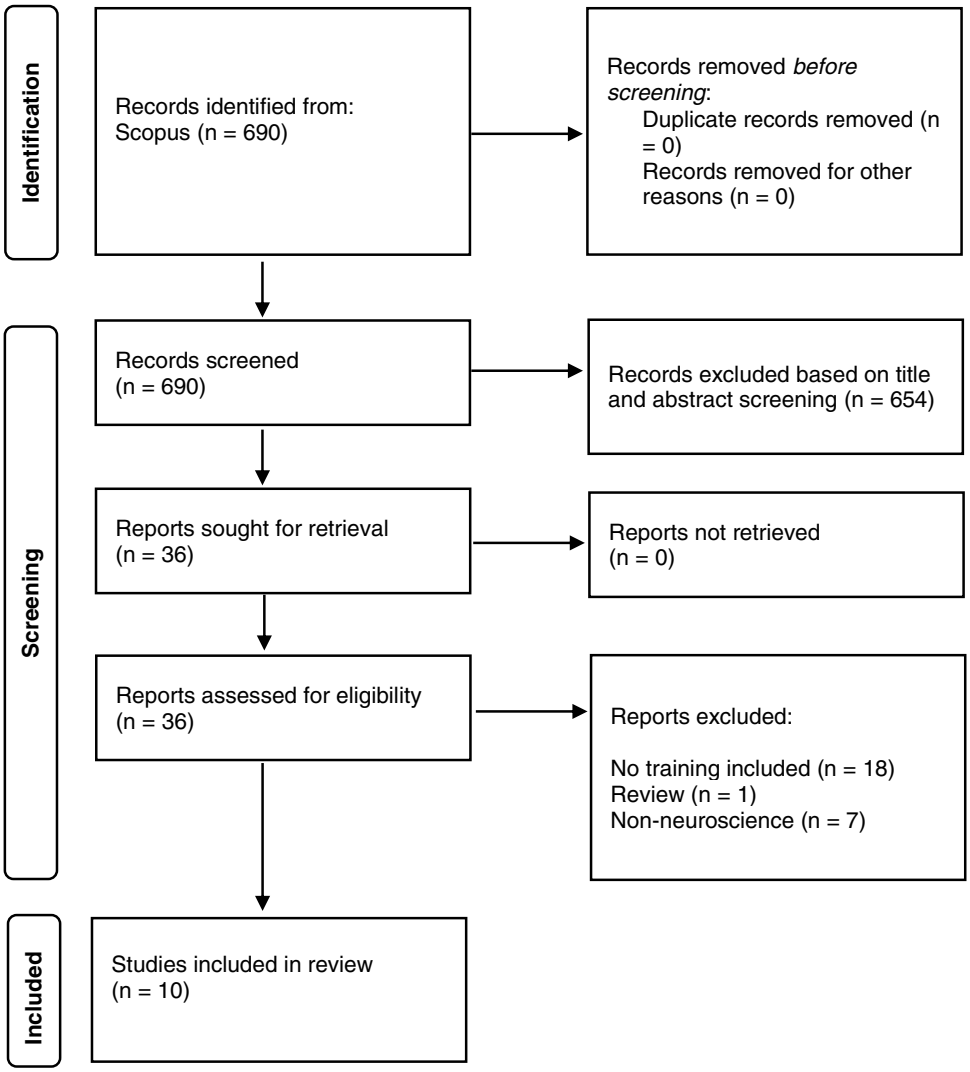


Fig. 1. PRISMA flow diagram.

data from each included study. For each article, the year of publication, population studied (e.g., pre-service teachers), training format (e.g., workshop), duration of training, scope of training, and main results were extracted. Extracted data are presented in Table 1.

3.6. Reporting of results

It was expected, due to differences in methodologies used in the identified studies, that data would be unable to be analysed quantitatively. Because of this, results are summarized in table format (Table 1) and are qualitatively summarized in text to provide an overview of the collective findings. Presentation of results was not limited to any one outcome (e.g., decrease in the belief of neuromyths) in order to best reflect the diversity of findings in the published work.

4. Results

4.1. Search, article selection, and extracted data

The final search resulted in 690 items returned by Scopus. After the application of selection criteria, a total of 10 articles were identified for inclusion in the review (Fig. 1). The details of these articles are summarized in Table 1. The oldest of the included articles was published in 2006 and the newest in 2020. The majority of excluded articles discussed the potential role neuroscience could play in education from a strictly theoretical perspective or assessed the prevalence of neuromyths in different populations of teachers. One article that was initially included [15] was later excluded because it was found to provide a review of the results from two papers already selected for inclusion [38, 39]. Article screening and selection results were identical when the process was repeated a second time by the study author.

The majority of included studies (8/10 studies) were conducted using samples of in-service teachers, including primary (4/8 studies), middle (3/8 studies), and high school teachers (1/8 studies). Only one study in pre-service teachers [14] explicitly reported that participants were pre-service primary teachers. The training formats used included workshops (6/10 studies), learning studies (i.e., collaborative, teacher-led research model focused around a learning theory; 2/10 studies), undergraduate courses (1/10 studies) and blended programs which included online and face to face components (1/10 studies). The duration of these programs ranged from as little as 90 min, to as long as several hours spread over the course of many days, weeks, or months. All studies reported drawing from foundational neuroscience knowledge in the development of their training, with the concept of neural plasticity covered in all programs. Additional details from included studies can be found in Table 1.

Table 1
Summary of characteristics of included research studies.

Publication	Sample	Training Format	Duration	Scope	Assessment	Main Result(s)
MacNabb et al., 2006	In-service middle school science teachers ($n = 56$; USA)	Multi-session workshop	1–2 weeks & 1 day follow-up 1 year later with follow-up during the year	Foundational neuroscience concepts; inquiry-based investigations; neuroscience integration in curriculum.	Questionnaire	↑ confidence in ability to understand and teach neuroscience. ↑ time teaching neuroscience. ↑ plans to use hands-on and inquiry-based pedagogies.
Roehrig et al., 2012	In-service upper primary, middle, and high school science teachers ($n = 107$; USA)	Multiple, multi-session workshops	Single (2 weeks) & two additional (1 week each) over 3 years & 1–3 days follow-up 1 year after each workshop	Modified Society for Neuroscience Core Concepts; inquiry-based investigations; neuroscience integration in curriculum.	Questionnaire, content test, & classroom observation	↑ confidence in ability to understand and teach neuroscience. ↑ use of hands-on and inquiry-based pedagogies. ↑ authentic instruction.
Anderson et al., 2018	In-service 5th grade math teachers ($n = 40$; USA)	Blended programme	30–40 h class; 7 in-person meetings; monthly coaching	Foundational neuroscience concepts related to math education and mindset.	Questionnaire, classroom observation, student test score	↑ use of supportive, cognitively stimulating, student-centred pedagogy. ↑ student growth mathematical mindset. ↑ student scores on standardized math test.
Ergas et al., 2018	In-service middle school teachers ($n = 30$, 29–55 yrs; Israel)	Multi-session workshop	Five sessions over 3 months (AVG: 91 mins)	Foundational neuroscience; emotional styles of the brain theory [61] & contemplative brain investigations.	Reflective writing & concept mapping	↑ teacher growth mindset.
Im et al., 2018	Pre-service primary teachers (EXP $n = 50$, $M_{age}= 20.86$; CON $n = 49$, $M_{age}= 20.27$; S. Korea)	Undergraduate course	1 semester	Foundational neuroscience & educational psychology concepts.	Questionnaire	↑ neuroscience literacy. neuromyth belief.
Tan et al., 2019	In-service grade 1–6 teachers ($n = 8$; Canada)	Learning study	5 months	Neural network hypothesis; hierarchical relational binding theory; attention & awareness.	Interviews, classroom materials, & meeting notes	↑ teacher understanding of relationship between biology and pedagogy.
Schwartz et al., 2019	In-service teachers ($n = 14$; USA)	Multi-session workshop	12 days	Modified Society for Neuroscience Core Concepts (educational neuroscience).	Content test, questionnaire, & lesson plans	↑ neuroscience understanding. ↑ planned use of student-centred pedagogies.
Tan & Amiel, 2019	In-service grade 1–6 teachers ($n = 5$; Canada)	Learning study	Unclear	Neural network hypothesis; hierarchical relational binding theory; attention & awareness.	Interviews	↑ use of constructivist-framed pedagogy. ↓ use of didactic instruction.
McMahon et al., 2019	Pre-service teachers ($n = 130$, $M_{age} = 25.39$; UK)	Single workshop	1.5 h	Foundational neuroscience concepts; neuromyths.	Questionnaire	↓ neuromyth belief.
Howard-Jones et al., 2020	In-service teachers ($n = 585$, follow-up $n = 135$, $M_{age} = 41.66$; UK)	Single workshop	1.5 h	Foundational neuroscience concepts.	Questionnaire	↑ value of scientific concepts for teaching. ↓ value of performative concepts for teaching

Note. Duration listed includes either the time over which the training was delivered or the time of the actual training, depending on what was reported in the respective studies. Additionally, the scope and results listed are not exhaustive for any study. For these reasons, readers are asked to review the body of the present manuscript or the original studies for more detail. ↑: increase, ↓: decrease, : no change.

4.2. Summary of reported results of neuroscience training

4.2.1. Impact on neuroscience knowledge and belief in neuromyths

Improved performance on assessments of neuroscience content knowledge [14, 40], as well as increased reported confidence in understanding and teaching neuroscience concepts [38, 39] have been reported after participation in neuroscience teacher training programmes. These findings are not surprising given that these training programmes are rooted in foundational neuroscience concepts. While these results are likely only relevant for those teachers in the biological and social sciences who are explicitly covering neuroscience-related content in their courses, more general findings described in these studies are covered later (see Impact on Instructional Practice section).

Considering this increase in neuroscience knowledge, one might expect neuroscience training to reduce the prevalence of neuromyths among participating teachers. In one study, Im et al. [14] found that participating in an educational psychology course that included neuroscience topics reduced but did not eliminate belief in neuromyths in pre-service teachers from South Korea. Similar results were reported in a sample of British trainee teachers after the completion of a 90-minute workshop embedded within an initial teacher education programme [41]. These findings are troubling considering that one of the main aims of providing training of this kind is to reduce the perpetuation of neuromyths. However, it is an unrealistic expectation that a single course of study in neuroscience could address all neuromyths [42]. Although by no means a "magic bullet" against neuromyths, neuroscience training has the potential to reduce the pervasiveness of these misconceptions among teachers while simultaneously increasing neuroscience content knowledge and confidence in the ability to teach neuroscience.

4.2.2. Impact on instructional practice

Pedagogically, participation in neuroscience training has been reported to influence teachers' choice of instructional strategies. Studies assessing the impact of this training on teaching practice have reported post-training increases in self-reported use of hands-on, inquiry-based, and student-centred pedagogies [39, 40, 43, 44]. In one study, participating teachers reported revising their current lesson plans to reflect more student-centred pedagogy with 45.5% of all revision comments relating to neuroscience [40]. Given the concerns around the accuracy of self-reported instructional practices [45], it is unclear whether these reported changes reflect what actually happened in the classroom. Two studies [38, 46] addressed this issue directly through the use of

post-workshop classroom observations. In both studies, teachers participating in neuroscience training increased their use of student-centred pedagogies. Specifically, Roehrig et al. [38] found that teachers completing a 2-week neuroscience workshop earned higher ratings on Higher Order Thinking, Deep Knowledge, Substantive Conversations, and Connections to the World standards from the Standards of Authentic Classroom Instruction [47] when compared with control teachers. Ratings on these standards continued to increase for teachers participating in additional 1-week training workshops. It is worth noting that, while the studies included in the present review refer exclusively to the pedagogical impact of neuroscience training, the impact of this training is also evidenced in didactic strategies employed by participating teachers. These studies provide limited evidence that neuroscience training can have a measurable impact on classroom practice in participating teachers.

Reported increases in the adoption of student-centred instructional strategies support that participation in neuroscience training has the potential to provide more general benefits to teachers across a wide range of disciplines. A possible explanation for this finding could relate to insight into teaching practice gained from neuroscience training. In a case study assessing the impact of a neuroscience theory framed learning study, Tan et al. [44] found that teachers reported better understanding of the relationship between brain function and pedagogy (i.e., how the brain processes information and how factors such as emotion can influence that process). This understanding may have provided teachers with a new perspective from which to evaluate instructional decisions made in the classroom, supporting the adoption of more constructivist approaches (i.e., those that emphasize the integration of new knowledge with existing knowledge). A recently published study provides additional support for this explanation. In their work, Howard-Jones et al. [48] reported an increase in the perceived value of scientific concepts for teaching as well as a decrease in the value of performative concepts immediately after completion of a 90-minute workshop on the science of learning. This change was still present after a follow-up survey was administered to a subsample of workshop attendees 6–12 weeks later. Decreases in the perceived value of performative concepts (i.e., ideas related to "looking like a teacher" that are not necessarily effective in supporting learning) may result in teachers adopting more evidence-based strategies over ineffective alternatives. Together, these results suggest that providing teachers with an understanding of how learning occurs in the brain can increase interest in the adoption of more effective pedagogical and didactic strategies.

4.2.3. Impact on mindset

Mindset theory, specifically the concept of growth mindset, is intimately related to the core neuroscience concept of neuroplasticity [49]. While there is an abundance of research on mindset interventions in students, including those explicitly covering the concept of neuroplasticity [50], little is known about the impact of this neuroscience concept on teacher beliefs and behaviours. In one study, teachers participated in a neuroscience workshop which included not only lecture on the concept of neuroplasticity, but contemplative brain investigations, first-person, introspective experiences about brain research [51]. After completion of this 5-week programme, teacher discourse reflected a shift from a fixed mindset to a more growth-oriented one. A similar shift in mindset, specifically related to mathematics, was also reported in students after teachers completed a hybrid course on foundational neuroscience and math mindset which included supplemental instructional coaching [46]. Developing a growth mindset after participating in a neuroscience teacher workshop may not be widely reported simply because researchers are not assessing this change. It is worth noting that, while the endorsement of a growth mindset is not thought to have a negative impact, whether mindset interventions positively impact teacher and student performance remains controversial [52]. These findings support that exposing teachers to concepts in neuroscience, perhaps specifically to neuroplasticity, can support the development of a growth mindset not only in themselves, but in their students.

4.2.4. Impact on student achievement

Most research on neuroscience training for teachers limits the scope to those changes observed in teacher beliefs and behaviours. This leaves a void in our understanding of how these changes influence student achievement. Among the reviewed studies, only one included an assessment of how these changes in teachers impacted student achievement [46]. By introducing 5th grade math teachers to the concept of neuroplasticity, and additional concepts related to math education and mindset, these researchers observed a similar shift toward student-centred pedagogy as those previously reported. Additionally, students of teachers participating in this training outperformed control students on a standardized, summative math assessment (i.e., Smarter Balanced Assessment Consortium (SBAC) Summative Assessment for California). While this provides more support in favour of neuroscience training for teachers, the actual impact of this intervention cannot be isolated due to the inclusion of mathematics and mindset-related content, as well as supplemental instructional coaching for participating teachers. Taken together with the research described above, it is reasonable to expect that students could benefit academically from their teacher's participation in neuroscience training, although additional studies focused only on neuroscience training are needed before strong conclusions can be drawn.

5. Discussion

Limited research and the inclusion of non-neuroscience related topics in training workshops prevents strong conclusions from being drawn regarding the specific impact of neuroscience training for teachers. Despite these drawbacks, current research supports that introducing teachers to neuroscience concepts is, at a minimum, not harmful, and could potentially have positive impacts on teacher beliefs, instructional practices, and student achievement for both pre-service and in-service teachers across a wide range of grade levels and disciplines.

6. Developing neuroscience training for teachers

The proposal to include neuroscience and related concepts in teacher training should not be equated with training teachers as scientists. Teachers and scientists are fundamentally different professions with different focuses and goals. The skills developed in a scientist may be of little use to a classroom teacher, and vice versa. For this reason, it is important that neuroscience training for teachers be focused on the end goal of teaching, not research. A previous synthesis assessing the impact of teacher professional development found that programmes benefitting participants typically built on their prior learning in the context of their existing beliefs, values, and theories [53]. The presentation of neuroscience research focused on its application to teaching can better support teachers in making use of this important information within their familiar pedagogical framework [27].

Ideally, the development of neuroscience training for teachers would occur collaboratively between neuroscientists and teacher educators [48, 54] with a focus on those concepts most relevant to education. While neuroscientists are likely the best resource for accurate content knowledge about the brain, educators are crucial for identifying which aspects are most relevant for the context in which they will be applied. One available resource which has proven useful in guiding programme scope comes from the Society for Neuroscience's Neuroscience Core Concepts [55]. These concepts, developed by neuroscientists, are succinct and easily applied to the context of teaching and learning (e.g., life experiences change the nervous system). Previously, they have been used to develop neuroscience training programmes for teachers in two published studies [38, 40]. Of these core concepts, neuroplasticity was

the most frequently included, present in 100% of the reviewed teacher training programmes. This is perhaps due to the relevance of this concept to teaching and learning [56], as well as the belief that it is well positioned to transform the beliefs and behaviours of both teachers and students [15, 30]. The process of brain development has also previously been identified as highly-relevant for education [38]. Limiting the scope of training to those concepts that are most relevant to teachers, presented within the context of teaching and learning, could support the maximum possible benefit of such training.

One important consideration is to minimize the "dumbing down" of neuroscience information for teachers beyond what is needed to support accessibility for non-experts [57]. While neuroscientists and teachers operate within different domains of expertise, both are equal parties supporting the bridge between their respective fields. Through thoughtful and respectful collaboration, scientifically accurate and pedagogically relevant training can be developed, providing teachers with information that is most applicable given the focus of their profession.

Policy makers and administrators interested in adopting neuroscience training will find their proposals in competition with other worthwhile professional development offerings. Given the limited amount of time available for professional development each year, neuroscience training for teachers must be thoughtfully designed to provide the maximum impact in the shortest amount of time. Previous studies have reported positive outcomes after participation in programmes ranging in duration from as little as 90 min [48] to 160 h over a 3-year period [38] for in-service teachers, and from 90 min [41] to over a semester [14] for pre-service teachers. The content of the longest duration workshop previously implemented (i.e., 160 h over a 3-year period) was derived from the Society for Neuroscience's Neuroscience Core Concepts [38, 55]. However, these same Core Concepts have also been used to develop an impactful training programme delivered over a significantly shorter period of time (i.e., 36 h) [40]. While there are no prescriptive guidelines on the ideal duration of this training, previous work supports that even short workshops (e.g., 90 min) can result in positive benefits for teachers. However, any training programme delivered should be of sufficient length in order to result in actual change [29].

Finally, it is worth commenting on the format of neuroscience training for teachers. The majority of previous studies utilized either a single workshop format [41, 48], multi-session workshop format [38, 39, 51], or university course format [14, 40, 46]. In a movement away from this trend, two recent studies have employed the use of a professional development model more commonly found in education: the learning study [58]. In two case studies of primary teachers in British Columbia, researchers utilized a neuroscience theory-framed learning study approach to support teachers in applying neuroscience to their classroom practice [43, 44]. This reflective, collaborative programme resulted in participants reporting a shift toward more constructivist-framed pedagogy and the use of more diverse instructional strategies in the classroom. Benefits of the learning study format could stem from its reflective, collaborative, non-prescriptive nature, empowering teachers to identify connections between neuroscience and pedagogy [30], and validating familiar theoretical models of learning [40]. Independent of the scope and duration of a neuroscience training programme, a variety of formats commonly used in other areas of teacher professional development are suitable for the delivery of this training.

7. Considerations for future studies

While interest in including neuroscience in teacher education is by no means new, the study of the impact of such training is still in its infancy. To provide an accurate assessment of the true impact of this training to best guide future work, a few important issues must be addressed. The first issue relates to the methodology used to study the impact of these training programmes. With perhaps two notable exceptions [14, 38] studies assessing the impact of neuroscience training for teachers do not regularly employ the use of control groups. This methodological oversight prevents conclusions from being drawn about the actual impact of these training programmes and is not aligned with best practices in the assessment of teacher professional development [59].

In many cases, the previously studied workshops were not exclusively focused of neuroscience. While there is some degree of overlap between the fields of neuroscience, cognitive psychology, and science of learning, to say that these workshops are truly focused on neuroscience is misleading. It is also the case that some studies included additional supports beyond a neuroscience workshop that could explain any possible reported benefits including supplemental instruction coaching [46], collaborative learning studies [43, 44], or classroom observations [38, 46]. These additional factors prevent conclusions about the specific impact of neuroscience training for teachers from being drawn from currently published studies.

While a handful of studies reported changes in teacher beliefs, few assessed whether training participation actually change teacher behaviour. Studies exploring the impact of this training on teacher behaviour should consider including student-level measures as there is some support for benefits that extend beyond the teacher [46]. Additionally, with one possible exception [48], the included studies did not directly assess how long the positive benefits of training lasted. The design of studies focused on the impact and longevity of effect of neuroscience training on teacher and student-level variables with appropriate controls in place will strengthen the conclusions that can be drawn from future research in this area.

Finally, it is unclear which teachers benefit most from neuroscience training. Previous work has assessed the impact of training workshops on both pre-service [14, 41] and in-service teachers [38-40, 43, 44, 46, 48, 51], reporting positive benefits for both groups. Considering that the benefits of professional development may differ as a consequence of the beliefs and values held by teachers [53], as well as the influence of age and experience on the willingness to participate in professional development [60], it could be the case that certain groups of teachers benefit more from neuroscience training than others. While the question has not been previously explored, it is believed that neuroscience training may be especially beneficial for teachers working with populations of students with major individual differences and diverse educational needs [31]. Exploring this topic is especially important in light of the limited amount of time available for teachers to participate in professional development.

There is work to be done in order for strong conclusions to be drawn about the effectiveness of neuroscience training for teachers. The adoption of more sound research designs including the comparison of training impact on different categories of teachers will provide more insight into whether these workshops are valuable, and how they can be most beneficial. Finally, more frequently extending the assessment of training effects into the area of student achievement will fill a significant void in the current literature.

8. Limitations of the present review

The present scoping review has a number of limitations that must be considered. First, after the application of inclusion and exclusion criteria, only 10 studies were included in the review. While this is not necessarily surprising considering that inquiry in this area is relatively new, it should be taken into consideration when interpreting the reported results. Identified studies showed a great deal of variability in their duration, scope, and population of interest, preventing strong conclusions from being drawn about the impact of this training. Included articles were limited to only those published in English, which may have led to an incomplete characterization of the current state of research in this field in countries where research is not regularly

published in English. Article selection and data extraction were performed by a single reviewer following explicit inclusion and exclusion criteria. While steps were taken in order to ensure that results were reproduceable (i.e., development of explicit selection criteria, article selection repeated twice, use of data extraction spreadsheet) there exists a possibility that results may have differed. Finally, only published studies were included, ignoring research in the grey literature.

Conclusion

It is unlikely that interest in bringing neuroscience into education will decrease in the future. Recently, the introduction of neuroscience concepts through teacher training has emerged as one possible path through which this can occur. The present scoping review identified what is believed to be an exhaustive list of English-language published studies on the impact of neuroscience training for teachers. The reported results support that the inclusion of neuroscience concepts in teacher training is a worthwhile endeavour that may positively impact both teacher practice and student achievement. However, limited evidence and methodological issues make it difficult to assess what the specific benefits of neuroscience training for teachers are. Only through the adoption of more sound methodology, including the use of appropriate controls, will future studies be able to draw sound conclusions about the true benefits of neuroscience training for teachers.

Ethical approval details

N/A

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Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication.

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