Neuroscience Integration in Secondary Education : A Bibliometric Analysis (1993-2025)

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ABSTRACT

Objective: This study aimed to explore the intersection of neuroscience and education by analyzing how neuroscientific research informs secondary education, particularly in relation to cognitive development, motivation, and learning strategies. **Method:** A bibliometric analysis of 218 articles indexed in the Scopus database from 1993 to 2025 was conducted. Keyword co-occurrence mapping, citation tracking, and publication trend analysis were performed using VOSviewer to identify core themes and leading contributors in the field. **Results:** Findings revealed a growing scholarly interest in applying neuroscience to education, especially in areas such as emotional and cognitive regulation, memory, and attention. Foundational studies from 2006 to 2012 remain influential, though the literature still lacks practical integration of neuroscientific findings into secondary-level teaching practices. **Novelty:** This study offers a structured overview of the educational neuroscience landscape with a unique focus on secondary education, highlighting the need for stronger interdisciplinary collaboration to bridge theory and practice and proposing that neuroscience-informed strategies can improve learning outcomes when aligned with classroom realities.

INTRODUCTION

The integration of neuroscience and education has undergone substantial evolution since the early 20th century, as the relevance of neurobiology to learning and teaching began to be acknowledged (Qiu & Johns, 2020). However, it was not until the 1990s designated the "Decade of the Brain" that technological advancements in live brain imaging catalyzed a significant surge in educational neuroscience research (Jones & Mendell, 1999). These developments laid the foundation for what is now widely recognized as educational neuroscience, a multidisciplinary field that aims to translate neuroscientific findings into applicable strategies for enhancing educational practices (Varma et al., 2008). Although debates continue regarding the efficacy and scope of neuroscience in addressing classroom challenges (Gabrieli, 2016; Gkintoni et al., 2023), global interest in this integration has remained strong, resulting in frameworks such as neuroeducation, brain-based learning, and mind-brain-education science.

Educational neuroscience has provided substantial insights into cognitive and emotional processes fundamental to learning, including attention, memory, executive function, and motivation (Gabrieli, 2016; Lazzaro et al., 2021; Petrican et al., 2021). These insights hold particular relevance for adolescents, whose brains undergo rapid development during secondary education. Research shows that improvements in executive function and emotional regulation can significantly enhance academic performance and student engagement (Feiler & Stabio, 2018; Martínez Vicente et al., 2023). Furthermore, neuroscientific interventions particularly those targeting working memory and attention are increasingly being explored as tools to support learners with diverse cognitive profiles (Gkintoni et al., 2023).

Despite growing enthusiasm, educational neuroscience remains theoretically complex and methodologically fragmented. Its inherently interdisciplinary nature

spanning cognitive psychology, neurobiology (Huffman & Stark, 2017), and pedagogy poses challenges in defining clear boundaries and standardizing research objectives. A major obstacle lies in translating brain imaging and cognitive science data into practical, scalable teaching approaches (Tolmie, 2015). The persistence of neuromyths, such as the misconception that individuals are strictly "left-brained" or "right-brained," further complicates the responsible application of neuroscience in classrooms (Beauchamp et al., 2019; Stein et al., 2012). Meanwhile, ethical concerns remain surrounding neuro-interventions that may influence children's biological development (D'Angiulli et al., 2012; Yu, 2023).

Laboratory-based neuroscience continues to advance in mapping cognitive functions linked to foundational academic skills, including literacy, numeracy, and problem solving. However, most of these advancements remain theoretical and have yet to be directly integrated into classroom practice, especially at the secondary education level (van Atteveldt et al., 2020). This disconnection highlights the need for translational strategies and collaboration between scientists and educators to bridge the research-practice divide. Educators and school psychologists equipped with both pedagogical and psychological literacy are uniquely positioned to mediate this interdisciplinary dialogue (Wilcox et al., 2021).

Given the global growth of neuroscience-informed education and its varied interpretations across disciplines, it becomes essential to map the landscape of existing research systematically. While many narrative and systematic reviews have explored the implications of neuroscience in early childhood or general education, there is a lack of large-scale, data-driven analyses that provide a comprehensive picture of how neuroscience research is evolving in relation to secondary education. Therefore, a bibliometric approach is appropriate for identifying major themes, clusters, and publication patterns, as well as for uncovering research gaps in this emerging field.

This study aims to conduct a bibliometric analysis of 227 Scopus-indexed articles published between 2016 and 2025 to explore how neuroscience research though often not directly framed within the context of secondary education can inform and be adapted to this educational level. The analysis includes keyword co-occurrence mapping, journal and country distributions, and publication trends over time. Given the scarcity of research explicitly linking neuroscience to secondary education, this study adopts a broader interpretive lens, identifying how general neuroscientific findings related to cognition, motivation, and learning can be translated into strategies relevant for adolescent learners. Through this approach, the study offers a macro-level understanding of the evolving landscape of neuroscience-informed education and suggests directions for future research and practice in secondary education contexts.

This study employed a bibliometric analysis to investigate global research trends in the field of neuroscience and its intersection with education. Bibliometric methods offer a macro-level, quantitative overview of research development by mapping the structure, distribution, and dynamics of scientific knowledge (Donthu et al., 2021; Zupic & Čater, 2015). Unlike systematic literature reviews that rely on full-text content evaluation and expert screening, bibliometric studies emphasize metadata analysis, including keywords, author affiliations, publication sources, and citation patterns. To enhance methodological transparency, the complete research workflow from database selection to analytical outputs is presented in Figure 1, outlining each step taken in the study.

RESEARCH METHOD

This study employed a bibliometric analysis to investigate global research trends in the field of neuroscience and its intersection with education. Bibliometric methods offer a macro-level, quantitative overview of research development by mapping the structure, distribution, and dynamics of scientific knowledge (Donthu et al., 2021; Zupic & Čater, 2015). Unlike systematic literature reviews that rely on full-text content evaluation and expert screening, bibliometric studies emphasize metadata analysis, including keywords, author affiliations, publication sources, and citation patterns. To enhance methodological transparency, the complete research workflow from database selection to analytical outputs is presented in Figure 1, outlining each step taken in the study.

Data Source and Search Strategy

The literature dataset was retrieved from the Scopus database, selected for its wide coverage of high-quality academic journals and robust citation indexing. A structured search was conducted on May 29, 2025, using a Boolean query designed to target articles related to neuroscience and its potential application in secondary education contexts. The search string used was: ("Neuroscience" OR "Brain science" OR "Neurobiology" OR "Cognitive science") AND ("Education" OR "Learning" OR "Teaching" OR "Instruction") AND ("High school" OR "Secondary education" OR "Teenagers" OR "Adolescents") AND ("Cognitive development" OR "Learning strategies" OR "Memory" OR "Attention") AND ("Motivation"OR "Engagement" OR "Achievement" OR "Performance"). This query yielded a total of 227 articles published between 1993 and 2025. No language or access filters were applied in order to maintain the comprehensiveness of the initial dataset.

Data Cleaning

After the dataset was exported in CSV format, a basic cleaning process was conducted to eliminate duplicate entries and ensure consistency in metadata fields. This process reduced the total number of records from 227 to 218 unique articles, which were then used for analysis.

Analysis Tools and Procedure

Bibliometric mapping and co-occurrence analysis were performed using VOSviewer (version 1.6.20), a software tool developed by the Centre for Science and Technology Studies, Leiden University (van Eck & Waltman, 2010). Descriptive statistics and bar charts were created using Microsoft Excel to support the visual interpretation of patterns. The analysis included the following components: keyword co-occurrence mapping, to identify dominant research clusters and emerging topics, journal and publisher visualization, to highlight leading publication venues, Annual publication trend analysis, from 1993 to 2025, Top 10 most cited years, based on cumulative citation counts, Top 10 contributing authors, based on publication frequency and country distribution, derived from institutional affiliations.

Scope and Limitations

Although the dataset includes neuroscience-related articles from various disciplines, not all articles explicitly discuss secondary education. As such, the study adopts an interpretive lens by identifying neuroscientific findings especially those concerning cognitive development, motivation, and learning strategies—that have potential relevance for secondary-level educational contexts. The inclusion of articles from

neuroscience, psychology, and medical science reflects the interdisciplinary nature of the field. This methodology provides a data-driven foundation to understand how neuroscience research may support pedagogical innovations, particularly for adolescent learners.
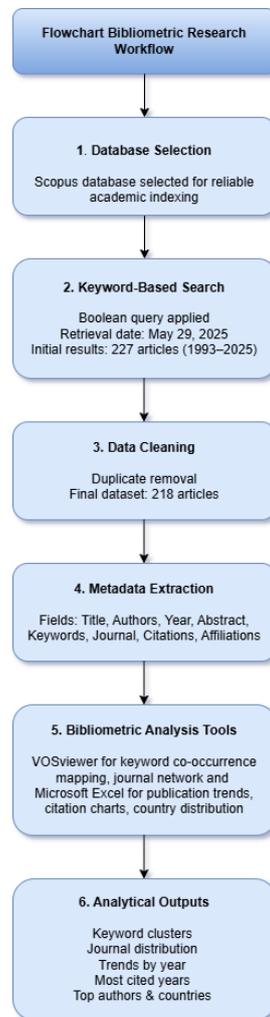

Figure 1. Flowchart of the bibliometric research workflow

RESULTS AND DISCUSSION

Results

Keyword Co-occurrence Mapping

To explore the conceptual structure of research on neuroscience and education, keyword co-occurrence mapping was conducted using VOSviewer based on author keywords from the collected articles. Two visualizations were generated to reflect both the initial dataset (227 articles) and the cleaned dataset (218 articles), as shown in Figure 2a and Figure 2b, respectively. These maps display clustered keyword networks, where the size of the nodes represents the frequency of each keyword, and the link strength reflects co-occurrence relationships among them. In the initial map (Figure 2a), central terms such as "human," "adolescent," "learning," and "attention" appeared prominently, forming the core of the red cluster. Supporting terms like "adult," "memory," and "brain mapping" emerged across other clusters. After duplicate

removal, the updated map (Figure 2b) revealed a slightly more refined network. The core keywords ("human," "adolescent," "memory," "neuroscience") remained dominant. The spatial rearrangement also indicated increased connectivity between "emotion," "motivation," and "education."
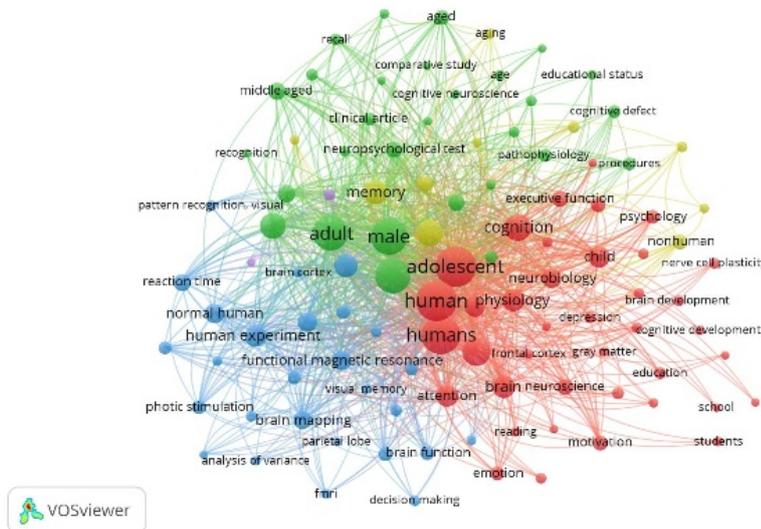

Figure 2a. Keyword co-occurrence network based on 227 articles (pre-cleaning dataset).
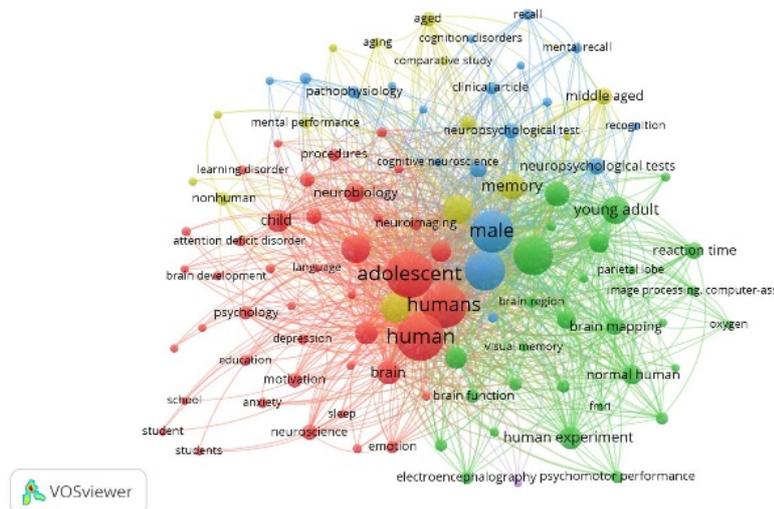

Figure 2b. Keyword co-occurrence network based on 218 articles (final dataset used for analysis).

Journal Contribution Mapping

To identify the most influential publication sources in the field of neuroscience and its intersection with education, a journal co-citation network was constructed using VOSviewer. Figure 3 visualizes the distribution and interconnection of journals based on citation data from the 218 selected articles. In this network, node size indicates the number of articles published or cited from each journal, while the thickness of the links reflects the strength of bibliographic coupling between journals. The visualization reveals that the Journal of Neuroscience occupies a central position in the network. Other prominent sources include the European Journal of Neuroscience, NeuroImage,

and Developmental Cognitive Neuroscience, which are tightly clustered within the same citation space. Additionally, journals such as Child and Adolescent Psychiatry and Frontiers in Human Neuroscience form a distinct secondary cluster. These results demonstrate that the most influential sources in the dataset are journals focused primarily on neuroscience and clinical domains.
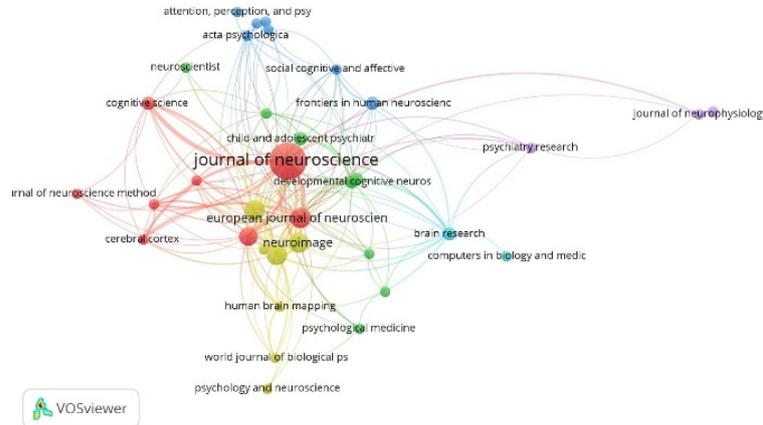

Figure 3. Journal co-citation network.

Annual Publication Trend

Figure 4 displays the annual distribution of publications from the Scopus dataset, encompassing 218 articles published between 1993 and 2025. The results reveal a progressive increase in research output over time, with notable growth in the past decade. Only one or two articles were published annually between 1993 and 2004, indicating limited early activity in neuroscience-related education research. A steady upward trend began in the early 2010s, with a marked surge starting in 2015. The number of publications peaked in 2017 with 17 articles, followed by a consistent annual output of over 10 articles through 2021. A second notable increase occurred in 2024, with 16 publications. As of May 2025, 8 articles had already been published, suggesting that the current year may continue the rising trend.
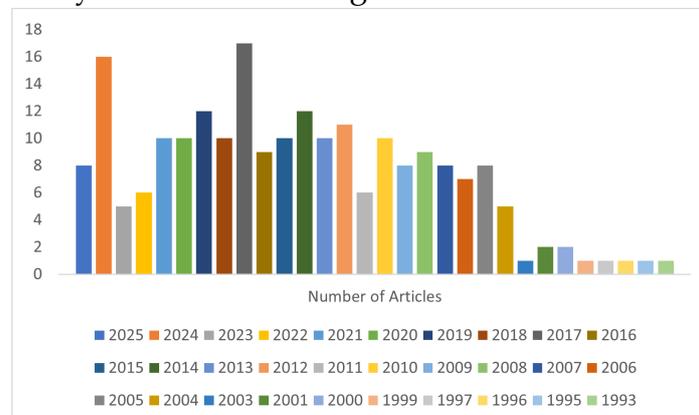

Figure 4. Annual distribution of neuroscience and education related publications from 1993 to 2025

Most Cited Years

Figure 5 presents the distribution of the most cited publication years based on the total number of citations received by articles within the dataset. The analysis highlights a concentration of high-impact publications between 2006 and 2012, with several years

significantly outperforming others in terms of cumulative citations. The year 2006 recorded the highest citation count, with over 1,600 citations, followed by 2010 with more than 1,000. Other years with notable citation counts include 2008, 2012, and 2013, each contributing between 400 and 600 citations. While recent years show a rise in the number of publications (as shown in Figure 4), their citation counts remain lower due to limited time for academic accumulation.
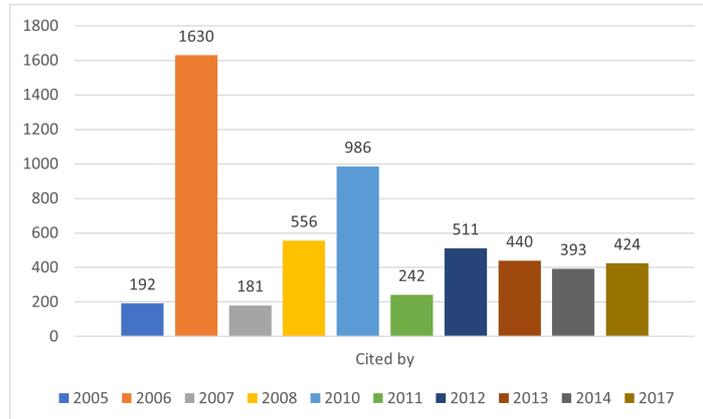

Figure 5. Most cited publication years based on total citation counts from articles in the dataset.

Table 1. List of Most Cited Articles in Key Publication Years

Nu	Authors	Title
1	(Fischer et al., 2005)	Motor memory consolidation in sleep shapes more effective neuronal representations
2	(Diseth & Christie, 2005)	Trauma-related dissociative (conversion) disorders in children and adolescents - An overview of assessment tools and treatment principles
3	(Allen et al., 2005)	An emotional mediation theory of differential age effects in episodic and semantic memories
4	(Gemma et al., 2005)	Improvement of memory for context by inhibition of caspase-1 in aged rats
5	(Katz et al., 2005)	Behavioral and neurobiological effects of printed word repetition in lexical decision and naming
6	(Smith & Squire, 2005)	Declarative memory, awareness, and transitive inference
7	(Facoetti et al., 2005)	Visual and auditory attentional capture are both sluggish in children with developmental dyslexia
8	(Agam et al., 2005)	Imitating unfamiliar sequences of connected linear motions
9	(Selenius et al., 2006)	Memory performance in dyslexic male juvenile delinquents convicted of severe offences does not differ from that in dyslexic male junior college students
10	(K. I. Taylor et al., 2006)	Binding crossmodal object features in perirhinal cortex
11	(Kalisch, Korenfeld, et al., 2006)	Context-dependent human extinction memory is mediated by a ventromedial prefrontal and hippocampal network
12	(Dolcos & McCarthy, 2006)	Brain systems mediating cognitive interference by emotional distraction
13	(Kalisch, Wiech, et al., 2006)	Levels of appraisal: A medial prefrontal role in high-level appraisal of emotional material
14	(Blair, 2006)	How similar are fluid cognition and general intelligence? A developmental neuroscience perspective on fluid cognition as an aspect of human cognitive ability
15	(Graham et al., 2006)	Abnormal categorization and perceptual learning in patients with hippocampal damage

Nu	Authors	Title
16	(Parris et al., 2007)	The role of the lateral prefrontal cortex and anterior cingulate in stimulus-response association reversals
17	(Feredoes et al., 2007)	The neural bases of the short-term storage of verbal information are anatomically variable across individuals
18	(Sher, 2007)	Functional magnetic resonance imaging in studies of the neurobiology of suicidal behavior in adolescents with alcohol use disorders
19	(Jacobsen et al., 2007)	Prenatal and adolescent exposure to tobacco smoke modulates the development of white matter microstructure
20	(Cannizzaro et al., 2007)	Effects of pre- and postnatal exposure to 5-methoxytryptamine and early handling on an object-place association learning task in adolescent rat offspring
21	(Hadipour-Niktarash et al., 2007)	Impairment of retention but not acquisition of a visuomotor skill through time-dependent disruption of primary motor cortex
22	(Song et al., 2007)	Sleep does not benefit probabilistic motor sequence learning
23	(Nomura et al., 2007)	Neural correlates of rule-based and information-integration visual category learning
24	(Mars et al., 2008)	Trial-by-trial fluctuations in the event-related electroencephalogram reflect dynamic changes in the degree of surprise
25	(Shaywitz & Shaywitz, 2008)	Paying attention to reading: The neurobiology of reading and dyslexia
26	(Zeithamova et al., 2008)	Dissociable prototype learning systems: Evidence from brain imaging and behavior
27	(Loveland et al., 2008)	Fronto-limbic functioning in children and adolescents with and without autism
28	(Kuhl et al., 2008)	Overcoming suppression in order to remember: Contributions from anterior cingulate and ventrolateral prefrontal cortex
29	(Lubman & Yucel, 2008)	'Adolescent substance use and the developing brain'
30	(Dretsch & Tipples, 2008)	Working memory involved in predicting future outcomes based on past experiences
31	(Cardinali, 2008)	Chronoeducation: How the biological clock influences the learning process
32	(Van den Bussche et al., 2008)	Conscious and unconscious proportion effects in masked priming
33	(Koenigsberg et al., 2010)	Neural correlates of using distancing to regulate emotional responses to social situations
34	(Yokoyama et al., 2010)	Right frontopolar cortex activity correlates with reliability of retrospective rating of confidence in short-term recognition memory performance
35	(Redcay et al., 2010)	Live face-to-face interaction during fMRI: A new tool for social cognitive neuroscience
36	(Rabelo et al., 2010)	Color trails test: A Brazilian normative sample
37	(Kar et al., 2010)	Neuropsychological lateralization of brain dysfunction in children with mesial temporal sclerosis: A presurgical evaluation
38	(Casey et al., 2010)	Adolescence: What Do Transmission, Transition, and Translation Have to Do with it?
39	(Vladusich et al., 2010)	Prototypical category learning in high-functioning autism
40	(Somerville & Casey, 2010)	Developmental neurobiology of cognitive control and motivational systems
41	(Shen et al., 2010)	GABA receptors and learning deficits at puberty in Mice
42	(Magalhães & Hamdan, 2010)	The rey auditory verbal learning test: Normative data for the brazilian population and analysis of the influence of demographic variables
43	(Ernst et al., 2011)	New perspectives on adolescent motivated behavior: Attention and conditioning
44	(Mcallister et al., 2011)	Cortical oscillatory activity and the induction of plasticity in the human motor cortex

Nu	Authors	Title
45	(Waxer & Morton, 2011)	Multiple processes underlying dimensional change card sort performance: A developmental electrophysiological investigation
46	(Paulo et al., 2011)	Patterns of cognitive performance in healthy ageing in northern portugal: A cross-sectional analysis
47	(Geary, 2011)	Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics
48	(Banner et al., 2011)	The brain-derived neurotrophic factor Val66Met polymorphism is associated with reduced functional magnetic resonance imaging activity in the hippocampus and increased use of caudate nucleus-dependent strategies in a human virtual navigation task
49	(Faugeras et al., 2012)	Event related potentials elicited by violations of auditory regularities in patients with impaired consciousness
50	(M. D. Lieberman, 2012)	Education and the social brain
51	(Pattanayak et al., 2012)	Neuropsychological performance in euthymic Indian patients with bipolar disorder type I: Correlation between quality of life and global functioning
52	(Bitan & Booth, 2012)	Offline Improvement in Learning to Read a Novel Orthography Depends on Direct Letter Instruction
53	(Baker et al., 2012)	An envisioned bridge: Schooling as a neurocognitive developmental institution
54	(Collins & Frank, 2012)	How much of reinforcement learning is working memory, not reinforcement learning? A behavioral, computational, and neurogenetic analysis
55	(Arciuli & Simpson, 2012)	Statistical Learning Is Related to Reading Ability in Children and Adults
56	(Wimmer et al., 2012)	Generalization of value in reinforcement learning by humans
57	(Klasen et al., 2012)	Neural contributions to flow experience during video game playing
58	(Gazendam & Kindt, 2012)	Worrying affects associative fear learning: A startle fear conditioning study
59	(Meng et al., 2012)	Event-related potentials in adolescents with different cognitive styles: Field dependence and field independence
60	(Snowball et al., 2013)	Long-term enhancement of brain function and cognition using cognitive training and brain stimulation
61	(Leisman et al., 2013)	The integration of the neurosciences, child public health, and education practice: Hemisphere-specific remediation strategies as a discipline partnered rehabilitation tool in ADD/ADHD
62	(Marco et al., 2013)	Maternal deprivation effects on brain plasticity and recognition memory in adolescent male and female rats
63	(Rubia, 2013)	Functional brain imaging across development
64	(Leynes & Kakadia, 2013)	Variations in retrieval monitoring during action memory judgments: Evidence from event-related potentials (ERPs)
65	(Miller et al., 2013)	Comprehensive Assessment of Child and Adolescent Memory: The Wide Range Assessment of Memory and Learning, the Test of Memory and Learning, and the California Verbal Learning Test-Children's Version
66	(Sherry, 2013)	The challenge of audience reception: A developmental model for educational game engagement
67	(Gjersoe & Hood, 2013)	Changing children's understanding of the brain: A longitudinal study of the royal institution christmas lectures as a measure of public engagement
68	(Meuwese et al., 2013)	Does perceptual learning require consciousness or attention?
69	(Pareés et al., 2013)	Failure of explicit movement control in patients with functional motor symptoms
70	(Shafto et al., 2014)	The Cambridge Centre for Ageing and Neuroscience (Cam-CAN)

Nu	Authors	Title
		study protocol: A cross-sectional, lifespan, multidisciplinary examination of healthy cognitive ageing
71	(Gansler et al., 2014)	Cognitive estimation and its assessment
72	(Schaeffer et al., 2014)	An fNIRS investigation of associative recognition in the prefrontal cortex with a rapid event-related design
73	(Sylva, 2014)	The role of families and pre-school in educational disadvantage
74	(Baune et al., 2014)	Neuropsychological functioning in adolescents and young adults with major depressive disorder - A review
75	(Coke-Murphy et al., 2014)	Simple shelter-style environmental enrichment alters behavior in mice
76	(Stubenrauch et al., 2014)	From brain imaging to good teaching? Implications from neuroscience for research on learning and instruction
77	(Wee et al., 2014)	Diagnosis of autism spectrum disorders using regional and interregional morphological features
78	(Urban & Gao, 2014)	Performance enhancement at the cost of potential brain plasticity: Neural ramifications of nootropic drugs in the healthy developing brain
79	(Toazza et al., 2014)	Phonemic verbal fluency is associated with pediatric anxiety disorders: Evidence from a community study
80	(Huffman & Stark, 2017)	The influence of low-level stimulus features on the representation of contexts, items, and their mnemonic associations
81	(Melchers et al., 2017)	The OXTR gene, implicit learning and social processing: Does empathy evolve from perceptual skills for details?
82	(G. & C., 2017)	1st International Conference on Brain Function Assessment in Learning, BFAL 2017
83	(J. S. Lieberman et al., 2017)	A tale of two temporal coding strategies: Common and dissociable brain regions involved in recency versus associative temporal order retrieval strategies
84	(Greeley & Seidler, 2017)	Mood induction effects on motor sequence learning and stop signal reaction time
85	(Ekhtiari et al., 2017)	Neuroscience-informed psychoeducation for addiction medicine: A neurocognitive perspective
86	(McDougle et al., 2017)	Implications of plan-based generalization in sensorimotor adaptation
87	(Schoenfeld et al., 2017)	Variations of the Morris water maze task to comparatively assess human and rodent place navigation
88	(Meeusen et al., 2017)	Physical activity and educational achievement: Insights from exercise neuroscience
89	(Fournier et al., 2017)	Effects of psychosocial stress on the goal-directed and habit memory systems during learning and later execution
90	(Liu et al., 2017)	Parahippocampal and entorhinal resection extent predicts verbal memory decline in an epilepsy surgery cohort
91	(Nock et al., 2017)	Neurobiology of substance use in adolescents and potential therapeutic effects of exercise for prevention and treatment of substance use disorders
92	(Piekarski et al., 2017)	Does puberty mark a transition in sensitive periods for plasticity in the associative neocortex?
93	(J. R. Taylor et al., 2017)	The Cambridge Centre for Ageing and Neuroscience (Cam-CAN) data repository: Structural and functional MRI, MEG, and cognitive data from a cross-sectional adult lifespan sample
94	(Kraus & White-Schwoch, 2017)	Neurobiology of Everyday Communication: What Have We Learned from Music?
95	(Enns et al., 2017)	Training and the attentional blink: Raising the ceiling does not remove the limits
96	(Khanmohammadi, 2017)	An improved synchronization likelihood method for quantifying neuronal synchrony

Most Cited Authors

Figure 6 illustrates the top ten authors whose publications received the highest citation counts within the bibliometric dataset. This metric is used to identify key contributors whose research has had a broad influence on the intersection of neuroscience and education. The most cited author is Dolcos F (Dolcos & McCarthy, 2006)., with a total of 533 citations, followed by Somerville L.H (Somerville & Casey, 2010) (498 citations) and Taylor J.R (K. I. Taylor et al., 2006) (424 citations). Other highly cited authors include Kalisch R (Kalisch, Korenfeld, et al., 2006) (409), Shafto M.A (Shafto et al., 2014) (393), and Shaywitz S.E (Shaywitz & Shaywitz, 2008) (362). Additional contributors in the top ten are Blair C. (316), Collins A.G.E. (287), Redcay E. (269), and Snowball A. (245).
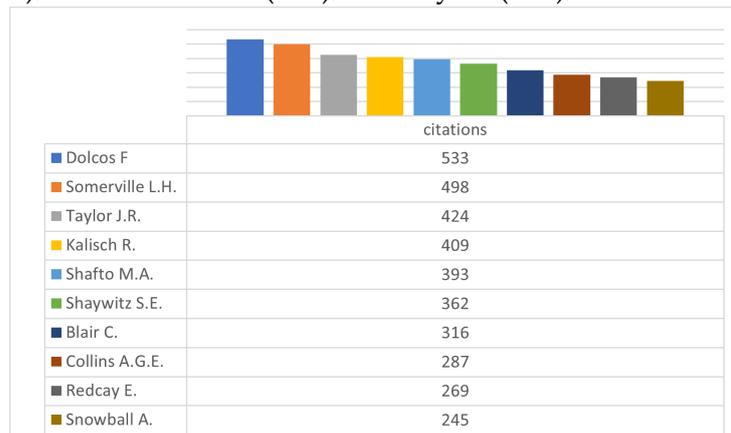

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Shaywitz S.E.	362
Blair C.	316
Collins A.G.E.	287
Redcay E.	269
Snowball A.	245

Figure 6. Most cited authors based on total citation counts from articles in the dataset.

Country Distribution
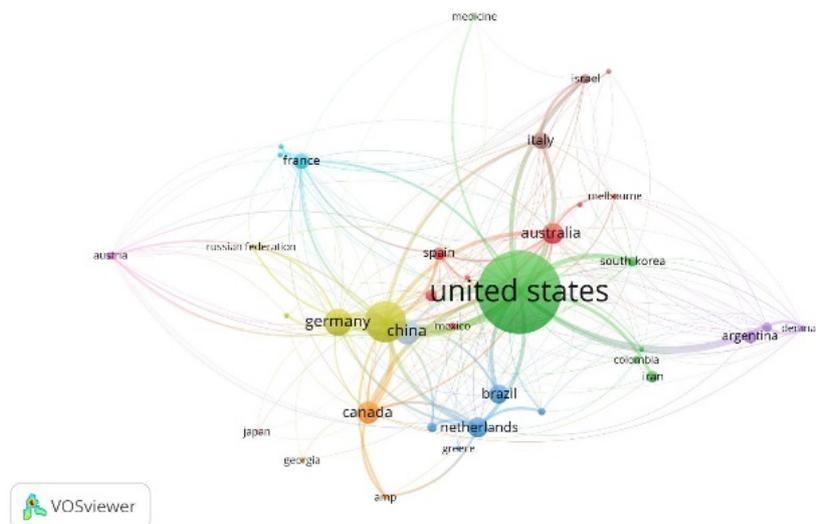
Figure 7. Geographic distribution of publications

Figure 7 illustrates the co-authorship network based on country distribution. The United States holds a dominant position, as indicated by its central location and the largest node size in the network visualization. This suggests that the United States not only contributes the highest number of publications but also engages extensively in international collaborations. Other major contributing countries include Germany, China, Canada, Australia, France, and the Netherlands, all of which show strong

collaboration clusters, as reflected by the thickness of the connecting lines (link strength) and node sizes. Countries such as Brazil, Italy, South Korea, and Spain also maintain a notable presence in terms of both publication output and international cooperation. Although smaller in node size, countries like Argentina, Denmark, and Israel exhibit visible collaborative ties. The cluster colors indicate regional or thematic collaboration groupings: the green cluster (e.g., United States, South Korea, Colombia) reflects high centrality; the yellow cluster (e.g., Germany, China) shows strong bilateral partnerships; while the blue and red clusters represent regional hubs such as Brazil and Australia.

Discussion

Keyword Co-occurrence Mapping
The keyword co-occurrence maps demonstrate a dominant focus on cognitive and behavioral dimensions of brain-based learning, particularly adolescent development, attention, and memory. Terms such as "human," "learning," and "adolescent" serve as conceptual anchors in the field, reflecting a neuroscience orientation grounded in cognitive psychology and neurobiology.However, keywords directly related to pedagogical practice—such as "school," "students," "education," and "academic achievement"—appeared relatively small and peripheral. Even after refining the dataset, terms like "secondary education," "learning strategies," and "teaching" remained underrepresented. This pattern reinforces the observation that research at the intersection of neuroscience and education tends to emphasize biological mechanisms over practical classroom application. Overall, these findings reveal a significant research gap in connecting neuroscience insights to secondary-level pedagogy. While the field has established a strong scientific base in understanding adolescent cognitive functions, it has yet to translate these findings into educational strategies and teaching practices. The maps support the argument that more interdisciplinary efforts are needed to align neuroscience with instructional design, student motivation, and real-world learning contexts.

Journal Contribution Mapping
The journal co-citation network highlights the dominance of journals centered on foundational and experimental neuroscience, particularly in areas such as brain imaging, cognitive development, and neurobiological mechanisms. The centrality of the Journal of Neuroscience and closely associated titles reflects the field's deep grounding in biological and cognitive sciences. However, the notable absence of education-focused journals especially those addressing secondary education points to a disconnect between neuroscience research and pedagogical discourse. This observation aligns with findings from the keyword analysis, which also showed low representation of education-related terms. It suggests that while neuroscience research relevant to learning and development is extensive, its dissemination rarely occurs through educational research outlets. The lack of interdisciplinary publication pathways may hinder the practical application of neuroscientific insights in real-world classroom contexts. Therefore, fostering collaboration between neuroscience and education journals could facilitate more effective integration of research findings into educational theory, teacher training, and instructional design.

Annual Publication Trend

The annual publication trend indicates growing scholarly interest in the intersection between neuroscience and education, particularly after 2010. The sharp increase in research activity from 2015 onward coincides with several key developments: the broader adoption of neuroimaging tools, increased funding for cognitive science research, and a rising demand for interdisciplinary approaches in educational policy and practice. The peak in 2017, and the resurgence in 2024, suggest that educational neuroscience is experiencing periodic momentum driven by thematic shifts or funding cycles. The data also highlight the relatively recent emergence of this research area. The low publication output prior to 2010 confirms that educational neuroscience is still maturing as a field and that its integration into practical teaching frameworks especially in secondary education remains a developing endeavor. This upward trajectory underscores the field's potential but also calls attention to the need for more targeted studies that directly link neuroscience findings to classroom application, teacher training, and student learning strategies.

Most Cited Years

The concentration of citations in the years 2006 to 2012 suggests a foundational period for research linking neuroscience and education. The exceptionally high citation count in 2006 indicates the presence of landmark publications that introduced or popularized key theories and methodologies, such as brain-based learning models, neuroimaging applications, and emotional-cognitive interactions. The surge in 2010 likely corresponds to technological and methodological advances in cognitive neuroscience, including increased use of fMRI and EEG in educational research. Notably, the years 2008, 2012, and 2013 also contributed significantly, reflecting a sustained interest in applying neuroscience principles to learning and development during that era. While more recent years have not yet accumulated comparable citation counts, their growing publication volume indicates renewed momentum in the field. In particular, 2017 stands out not for its cumulative citations but for the quantity of influential articles it contributed, suggesting a resurgence of interdisciplinary research efforts. These findings are further detailed in Table 1, which compiles the most cited articles from 2005 to 2013, alongside a notable cluster from 2017. The enduring influence of these works highlights their role as conceptual anchors in educational neuroscience and underscores the importance of historically foundational research, even as new directions continue to emerge.

Most Cited Authors

The citation prominence of these authors highlights their sustained scholarly impact in shaping the discourse on neuroscience and education. For example, Dolcos and Somerville are widely recognized for their research on cognitive and emotional regulation core themes that underpin many neuroscience-informed educational strategies. Their work has helped to elucidate how emotional states affect learning processes, particularly in adolescent populations. Authors like Taylor and Kalisch have contributed significantly to our understanding of brain function and neuroplasticity, laying the groundwork for applying neuroscientific insights to cognitive training and educational design. Similarly, Shaywitz is known for foundational research in the neurobiology of dyslexia and reading development, which has had a direct influence on special education approaches. The presence of Blair, Collins, Redcay, and Snowball

further reflects the expanding interest in linking motivation, memory, and learning strategies with real-world educational practices. These authors often bridge cognitive neuroscience with instructional applications, positioning their research at the nexus of brain science and classroom innovation. Collectively, the high citation counts of these authors indicate that the field continues to be shaped by a relatively small group of interdisciplinary researchers whose work resonates across psychology, neuroscience, and education. Their continued influence underscores the importance of integrating cognitive science findings into the development of evidence-based teaching methods.

Country Distribution

The country level analysis underscores the central role of the United States in shaping the global research agenda in neuroscience and education. Its position as both a major producer of scholarly output and a central collaborator signals its leadership in driving interdisciplinary research across borders.The strong presence of Germany, China, and Australia further highlights the global nature of the field. These countries have invested significantly in neuroscience and cognitive science infrastructure, often integrating this research into educational initiatives. Their involvement in bilateral and multilateral collaborations expands the diversity and applicability of research outcomes. Interestingly, the inclusion of countries from South America (e.g., Brazil, Argentina), Europe (e.g., Italy, France, Spain, Denmark), and the Middle East (e.g., Israel) reflects a widening of the geographic scope of neuroscience-informed education studies. While these regions may have smaller publication outputs, their active participation in international networks contributes to a more inclusive and representative research ecosystem. The collaboration patterns also suggest that future progress in educational neuroscience will likely depend on sustained international partnerships, allowing for the exchange of context-sensitive insights and more robust cross-cultural validations of brain-based learning approaches.

CONCLUSION

Fundamental Finding : This study successfully applied bibliometric analysis to map the development of research at the intersection of neuroscience and education, particularly in the context of secondary education. By analyzing 218 articles from the Scopus database (1993–2025), the study revealed a growing body of literature focusing on adolescent cognitive development, emotional regulation, attention, and memory core components of learning processes. Keyword co-occurrence and citation mapping confirmed the dominance of cognitive neuroscience themes and identified influential contributors such as Dolcos, Somerville, and Taylor, whose work has significantly shaped this interdisciplinary field. However, the findings also highlight a persistent gap between neuroscience research and its direct application to classroom practices in secondary education. **Implication :** These findings underscore the importance of advancing educational neuroscience not only as a theoretical framework but also as a practical resource for teaching and learning. The limited integration of neuroscience into pedagogical strategies reflects a missed opportunity to enhance student outcomes through evidence-based instructional design. Addressing this gap requires deeper collaboration between researchers and practitioners to translate neuroscientific insights into actionable teaching strategies that respond to the cognitive and emotional needs of adolescents. Moreover, increased dissemination of neuroscience knowledge to

educators can counter the spread of neuromyths and promote more informed decision-making in curriculum development. **Limitation :** While the study offers a comprehensive overview of the research landscape, it is limited by its reliance on a single database (Scopus), which may exclude relevant studies indexed elsewhere. Additionally, citation-based metrics may favor older publications and high-profile authors, potentially underrepresenting emerging voices or localized research efforts in non-English-speaking contexts. The study also did not analyze full-text content, which might reveal deeper pedagogical linkages than keyword or citation data alone can capture. **Future Research :** Future research should focus on bridging the gap between theory and practice by developing and evaluating neuroscience-informed interventions in real classroom settings, especially at the secondary education level. Studies should also explore how emotional and cognitive regulation can be better supported through instructional strategies, curriculum design, and teacher training. Furthermore, interdisciplinary efforts must address ethical concerns around the use of neurotechnologies in education, ensuring that such innovations are applied responsibly and equitably. Expanding bibliometric studies to include emerging themes, cross-cultural perspectives, and diverse educational systems will also contribute to a more holistic understanding of how neuroscience can enhance learning globally.

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