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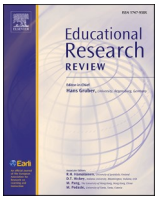

Review

Translating neuroscience to early childhood education: A scoping review of neuroscience-based professional learning for early childhood educators

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ABSTRACT

Over the past 20 years there has been a growing international focus within early childhood education sectors on the potential benefits of neuroscience-informed approaches. This has resulted in a burgeoning of initiatives that draw upon neuroscience to influence early childhood educator practice and, in turn, children's learning and development. This study reports an international scoping review of professional learning programs for early childhood educators that are based on the translation of neuroscience research to practice. A total of 15 studies were included with the professional learning approaches documented variously aiming to build educator knowledge, support educators to embed specific practices, and/or deliver a structured intervention with children. There were largely positive reports across studies of boosts in educator knowledge, attitudes, confidence, and self-efficacy in relation to neuroscience. In several studies, educators also reported changes to their practice, improvements in the quality of their relationships with children, and reduced stress levels. Child outcomes were less often reported, with two of the three studies reporting these documenting enhanced child social-emotional development from delivery of a specific intervention by educators. Implementation fidelity was an important aspect with high fidelity linked with better documented outcomes. Overall, the robustness of the evidence for neuroscience-based professional learning for early childhood educators is mixed, with the majority of included studies not including a comparison group, and thus causality cannot be claimed. We propose a theory of change model for this field of work, and note the current limited research focussed on outcomes beyond initial changes in educator attitudes and knowledge. There is potential for design of more comprehensive approaches to embed neuroscience in early childhood education. Future scaling up of effective programs, and design of new ones, requires deeper understanding of program implementation and points to the need for comprehensive evaluations incorporating both process and outcomes assessment.

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1. Background

Early childhood is a critical time for brain development. The past three decades have seen substantial growth in developmental neuroscience knowledge yielding greater understandings about how brain development in early childhood can set trajectories that influence lifelong development, learning, health, behaviour, and wellbeing (Goswami, 2006; Howard-Jones, 2014; Privitera, 2021; Shore, 1997; Thomas et al., 2019). At its simplest, neuroscience is the interdisciplinary study of the structure and function of the human brain and nervous system (Mustard, 2008). There is ongoing concern for how existing and emerging neuroscience evidence can be used to inform early childhood education and care practices to, in turn, support children's development and wellbeing. In this paper we report a scoping review of neuroscience-based professional learning programs for early childhood educators, establish their characteristics, and current evidence base.

1.1. Neuroscience-based professional learning for educators

The translation of findings from neuroscience to educational practice has been challenging and contentious (Bowers, 2016; Thomas et al., 2019) in part due to disciplinary and philosophical divides (Wilcox et al., 2021). For example, the science of the human brain, how it develops and is shaped, may be considered unnecessarily reductionist by scholars with a strong sociological standpoint that privileges the holistic nature of early development and its multiplicity of social and environmental influences (Boyle, 2019). The proliferation of neuromyths, or misunderstandings about the human brain, as part of a growing field of "neuroeducation" has also been held to scrutiny (Torrijos-Meulas et al., 2021) despite scholarship suggesting that beliefs in neuromyths may be "pedagogically harmless" (Privitera, 2021, p. 2). All things considered, the translation of the ever-growing knowledge of early brain development to both policy and early childhood practice remains a key challenge (Shonkoff & Levitt, 2010) and a priority reflected in contemporary early childhood education curriculum and learning frameworks (Australian Government Department of Education [AGDE], 2022a; New Zealand Ministry of Education, 2017). To bridge the divide, professional learning programs have been developed for the early childhood education and care (ECEC) sector in an effort to translate key neuroscience messages into digestible and actionable mechanisms for evidence-based practice.

Neuroscience-based professional learning programs are thought to work through the mechanism of changing educators' awareness, knowledge, and/or practices, for the ultimate benefit of children's learning and development. In this review, we classify programs according their 'approach' mechanism. First, some professional learning programs aim solely to enhance educator knowledge about the brain and how it works. These programs do not provide pedagogical tools or implementation resources. We characterise the approach of these programs as *increasing knowledge*. Second, some professional learning programs aim additionally to provide specific pedagogical tools for educators. These tools include strategies for interacting and responding to children that are thought to be helpful in building neural networks, and supporting health brain development overall, with implications for social-emotional and cognitive development among other developmental domains. We characterise the approach of these programs as teaching educators to *embed specific practices*. Third and finally, some professional learning programs train educators to *deliver structured interventions* with children, that have been developed based on neuroscience principles.

The overarching theory of change for neuroscience-based professional learning programs, must be built on existing theories of change in early childhood education (Blewitt et al., 2020; Muir et al., 2024). The hypothesis is that building educator awareness and knowledge will in turn influence educators' pedagogy and interactional styles with children (e.g., how stimuli are presented, expectations of children's response time, how behaviours are responded to) and this in turn should enhance child outcomes (such as social-emotional and cognitive skills) and, in some instances, educator outcomes (such as work satisfaction or wellbeing). Ultimately changes in practice (Muir et al., 2024), enhancements in educator wellbeing (Turner & Thielking, 2019) and child-teacher relationships (Early et al., 2017) or delivery of a specific intervention in some instances (Blewitt et al., 2019), is hypothesised to have important implications for children's learning overall (Blewitt et al., 2020; Muir et al., 2024). Whatever formulation of change mechanisms is used, it is clear that educators are central to the process, and by default, the quality and substance of their preparation and ongoing professional learning can also be viewed as fundamental (Brunsek et al., 2020).

While numerous neuroscience-informed professional learning initiatives have been developed and implemented with early childhood educators and children, little is known about their effectiveness overall, or the implementation factors that support outcomes for educators and/or children. To enhance future efforts to translate neuroscience to the ECEC sector, educators and policy makers require robust information about intervention purposes and core features, the presence or absence of evaluation studies indicating effectiveness, and the reliability and comprehensiveness of those evaluations. Given the apparent proliferation of neuroscience-informed professional learning programs in ECEC, it is also timely to consider the implementation factors associated with the best outcomes for educators and children. Knowing more about the enablers and barriers to uptake and effectiveness for these programs will help shape future directions for program designers and developers, and professional learning decision makers in early childhood sectors.

To our knowledge only one comprehensive review has been undertaken to date on neuroscience training interventions for educators (Privitera, 2021). Privitera (2021) conducted a scoping review of research in neuroscience training for pre-service and in-service elementary (primary), middle, and high (secondary) schoolteachers and administrators. Ten studies were included in the review, none of which reported an intervention for teachers in before-school early childhood settings (i.e., ECEC). Teacher training interventions were conducted as workshops, collaborative learning opportunities, and university courses, and ranged in duration from a single 90-min session to longer multi-session courses delivered over several months. Studies measured a wide range of teacher outcomes including neuroscience understanding (knowledge), confidence (self-efficacy), beliefs in neuromyths, mindsets, and pedagogical or

instructional practice. This current review provides an early childhood companion piece to Privitera's (2021) review.

1.2. The current study

Little is known about the nature and effectiveness of neuroscience based professional learning programs for early childhood educators in before-school settings. The current scoping review synthesizes the extant literature to answer the compound research question: What are the characteristics of neuroscience-based professional learning programs for ECEC educators, what approaches are taken? What is the evidence of their effectiveness?

2. Method

We conducted a scoping review of international scientific and grey literature to synthesise what is currently known about translating neuroscience to educational practice with educators working with young children in early childhood education. Our aim was to systematically "scope" the literature (Arksey and O'Malley, 2005; Tricco et al., 2018) by examining studies that had evaluated professional development programs used to translate neuroscience concepts into educational practice. We followed the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* extension for scoping reviews (PRISMA-ScR) (Tricco et al., 2018). Our review might best be classified as a 'rapid' scoping review. Owing to time limitations imposed by the funding agreement, we applied time-saving strategies such as developing but not registering the review protocol, restricting searches to only the most relevant databases, and not contacting study authors to supply information missing from study reports.

2.1. Searches and search strategy

To identify potentially relevant studies for inclusion, we searched four academic databases in June and July 2022: ERIC (via EBSCOhost), PsycINFO (via EBSCOhost), PubMed, and Scopus. Searches were limited to English language publications published during the past 20 years (i.e., from 2002 to 2022). A consistent set of database search terms were used, with minor variations such as MeSH or Subject Heading field searching as dictated by the specific platform. The full search strategy is recorded in Table 1. Results were exported from academic databases into Endnote 20.2.1 reference management software (Clarivate, 2021), deduplicated, and imported into Rayyan, a web and mobile app for systematic reviews (Ouzzani et al., 2016), where records were screened against inclusion criteria.

Reference lists of included studies were screened to identify additional studies and citation searches using Scopus and Google Scholar were conducted to identify further citing articles. We searched for grey literature in July and August 2022 using the Google Advanced search function with the search string: "(embed OR integrate) AND (neuroscience OR "brain development") AND ("early childhood education" OR "early years" OR childcare) with the Google feature "Personal results" turned off to limit algorithmic bias. Repositories for grey literature were also searched including OECD iLibrary, Australian Policy Online (APO), Policy commons, UNESCO Digital Library (https://unesdoc.unesco.org/), World Health Organization's Institutional Repository for Information Sharing (WHO | IRIS), the UK Education Endowment Foundation Repository, and the US 'What works' clearinghouse. Finally, in August 2022 we searched several global clinical trial registries including the US National Library of Medicine clinical trials register (www.clinicaltrials.gov), Current Controlled Trials (www.controlled-trials.com), and the Australian New Zealand Clinical Trials Registry (www.anzctr.org.au). Results of these searches were imported into Endnote and deduplicated before remaining records were imported into Rayyan for screening.

Table 1
Search strategy (June–July 2022).

Database	Example search statement	Results
ERIC (EBSCOhost)	SU (neurolog* OR neuroeducation OR neuroscience OR neurodevelopment OR brain OR mind OR "child development") AND (teacher or practitioner or educator) AND (training OR college OR degree OR "professional development") AND ("early childhood" OR "early years" Or preschool) LIMIT English LIMIT >2002	331
PsycINFO (EBSCOhost)	"Early childhood" OR kinder* OR childcare OR daycare OR preschool OR "Early education" OR "early years") AND (integrat* OR implement* OR translat* OR transfer OR training OR exchange OR mobili*ation OR sharing OR practice) AND (neurological OR neuroeducation OR neuroscience OR neurodevelopment OR brain OR mind OR "child development") AND (curriculum OR program* OR pedagog* OR instruction OR model) AND (evaluate OR appraise OR assess) NOT parent Narrow by Language: english Limit 2002–2022	194
PubMed	Search: "Child Development"[MAJR]) AND ("Child Day Care Centres"[MeSH]) OR "Child, Preschool"[MeSH]) AND ("Teacher Training/methods"[MAJR]) OR "School Teachers/psychology"[MAJR]) OR "Inservice Training/methods"[MAJR]) Filters: Randomized Controlled Trial, from 2002 to 2022	52
Scopus	(TITLE-ABS-KEY ("research -to-practice" OR translat* OR training OR program* OR "professional development" OR "knowledge transfer" OR "knowledge sharing" OR "teacher education" OR program* OR research) AND TITLE-ABS-KEY (neuroscience OR "brain development" OR neuroeducation) AND TITLE-ABS-KEY ("early childhood" OR "early years" OR daycare OR preschool OR childcare OR "early learning") AND TITLE-ABS-KEY (evaluat* OR effectiv*)) AND PUBYEAR >2001	259

2.2. Study inclusion and exclusion criteria

We included primary empirical studies reporting on the effectiveness of and/or implementation of professional learning programs designed to translate neuroscience to educational practices. We included studies in which the participants were (i) educators working in early childhood education in before-school settings (i.e., childcare, day care, kindergarten, preschool), or (ii) educators working in early childhood education in before-school settings alongside parents and/or children. We included any study designs inclusive of process and outcome evaluations. We excluded: studies with educators working in schools; studies reporting only child-related outcomes with no data collected in relation to educators and their professional learning, knowledge, or practices; studies describing neuroscience-based interventions but not reporting on their evaluation; and reviews.

2.3. Study selection

Titles and abstracts of records were screened by two reviewers working independently. Discrepancies were resolved through discussion. The full texts of potentially included studies were retrieved and screened by the same two reviewers. An Excel data extraction template was developed, tested, and refined using the first 5 included studies. Data were extracted by two reviewers working independently on different segments of the task. For consistency across studies, the first reviewer extracted data on all study characteristics, and study research design and methods, and the second reviewer extracted data on the characteristics of the intervention.

2.4. Critical appraisal

We used the Kmet et al. (2004) study appraisal tool which comprises 14 assessment criteria for evaluating the methodological quality of primary research papers with quantitative research designs (for example, was the study design evident and appropriate; were outcome measures well defined; were results reported in sufficient detail) and 10 assessment criteria for evaluating the quality of primary research papers with qualitative designs (for example, was the context for the study clear; was the sampling strategy described, relevant and justified; were conclusions supported by results). Studies using mixed methods were assessed against both sets of criteria. We rated each study against these criteria assigning scores according to the degree to which each criteria was met: a score of "2" (there was evidence in the research paper that the criteria was met, fully); a score of "1" (there was evidence in the research paper that the criteria was met, partially); a score of "0" (there was no evidence about this criteria in the research paper); and the annotation "n/a", was used to indicate that the criteria was not relevant to that study. Summary scores were calculated by summing total scores for each study and dividing by the number of relevant items. Irrelevant items were not scored and were excluded from the denominator.

2.5. Data analysis

Data analysis focused on answering the research questions. Synthesis took two broad approaches. The first was a descriptive analysis which summarised the results of the search strategy, selection, and classification process, and shows the PRISMA flow diagram (Fig. 1). The second was use of qualitative coding to identify emerging approaches to neuroscience translation, the outcomes assessed in approaches, the effectiveness of approaches, and implementation enablers and barriers.

3. Results

Searches of academic databases yielded 836 records. After de-duplication 433 titles and abstracts were screened for eligibility. Sixty-eight of these records progressed to full-text screening with 10 studies included. Searches via other methods yielded 5 further studies. The full review corpus comprised 15 studies. A PRISMA flow diagram is shown in Fig. 1.

Characteristics of included studies are summarised in Table 2. The methodological quality of the included studies was assessed against the Kmet et al. (2004) criteria. Overall, the assessment criteria were at least partially met in most studies, with only 1 of the 15 studies scoring less than 1. Fig. 2 shows results of the Kmet assessments for quantitative, mixed methods, and qualitative studies.

Results are presented below to answer the review's two-part research question. Sections 3.1 and 3.2 address 'what are the characteristics of neuroscience-based professional learning programs for ECEC educators and what approaches are taken?'. Sections 3.3 and 3.4 address 'what is the evidence of their effectiveness?'. Evidence of effectiveness is presented for both educator- and child-related outcomes. Section 3.5 synthesizes program implementation enablers and barriers as these may influence program effectiveness.

3.1. Characteristics of included studies

The oldest of the 15 included studies were published in 2015 (Archer & Siraj, 2015; Diamond & Whitington, 2015) and the most recent in 2023 (Williams et al., 2023a).[1] Studies were conducted in the USA (n = 7) (Anderson et al., 2020; Goble et al., 2021; Lang et al., 2020; Lashinsky, 2019; Nesbitt & Farran, 2021; Parr, 2016; Whitaker et al., 2019), Australia (n = 4) (Cartmel et al., 2021;

[1] A pre-publication version of this paper was identified to the research team during searches conducted in 2022. The final version has since been published (Williams et al., 2023a).

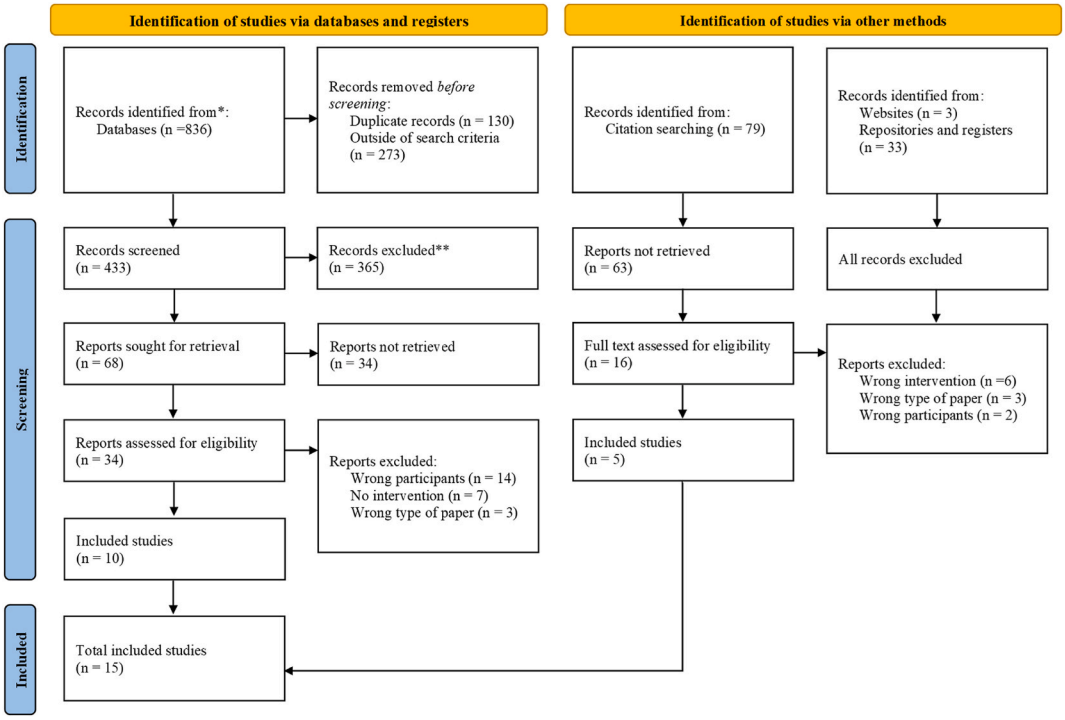

Fig. 1. Prisma flow diagram (Page et al., 2021).

Diamond & Whitington, 2015; Sexton et al., 2022; Williams et al., 2023a), the UK (n = 2) (Archer & Siraj, 2015; Howard-Jones et al., 2020), Canada (n = 1) (Diamond et al., 2019), and Israel (n = 1) (Luzzatto & Rusu, 2019). Studies were conducted with samples of educators from early childhood settings, variously described as kindergarten, preschool, childcare, and early childhood. Some studies also included K-6 (Lashinsky, 2019) and K-12 teachers (Howard-Jones et al., 2020; Parr, 2016). Two studies included preservice early childhood teachers (Diamond & Whitington, 2015; Luzzato & Rusu, 2019). Participant sample sizes ranged from nine (Diamond et al., 2019) to 585 (Howard-Jones et al., 2020). A majority of the fifteen included studies (n = 8) employed quantitative research designs (Anderson et al., 2020; Diamond et al., 2019; Goble et al., 2021; Howard-Jones et al., 2020; Lang et al., 2020; Nesbitt & Farran, 2021; Sexton et al., 2022; Williams et al., 2023a), with the remainder comprising mixed-methods (n = 6) (Archer & Siraj, 2015; Cartmel et al., 2021; Lashinsky, 2019; Luzzatto & Rusu, 2019; Parr, 2016; Whitaker et al., 2019), and qualitative research (n = 1) (Diamond & Whitington, 2015).

Quantitative designs were randomised controlled trials (n = 6) (Diamond et al., 2019; Goble et al., 2021; Herman & Whitaker, 2020; Nesbit & Farran, 2021; Sexton et al., 2022; Williams et al., 2023a), quasi-experimental (Archer & Siraj, 2015); and pre-test and post-test studies without control groups (n = 4) (Anderson et al., 2020; Howard-Jones et al., 2020; Lang et al., 2020; Lashinsky, 2019). Mixed method studies combined experimental approaches multifariously with interviews, focus groups, or observations (n = 5) (Archer & Siraj, 2015; Cartmel et al., 2021; Luzzatto & Rusu, 2020; Parr, 2016; Whitaker et al., 2019). The qualitative study (n = 1) comprised a thematic analysis of participant written comments to online discussion forums and course evaluations (Diamond & Whitington, 2015).

The studies assessed a range of outcomes including educator knowledge and confidence (self-efficacy) (n = 5) (Cartmel et al., 2021; Lang et al., 2020; Lashinsky, 2019; Parr, 2016; Williams et al., 2023a), implementation fidelity (n = 2) (Anderson et al., 2020; Nesbitt & Farran, 2021), perceived value or endorsement of the intervention (n = 3) (Diamond et al., 2019; Diamond & Whitington, 2015; Howard-Jones et al., 2020), relational capacities between educators and children (n = 2) (Archer & Siraj, 2015; Whitaker et al., 2019), intervention feasibility (n = 1) (Sexton et al., 2022), and educator characteristics (n = 1) (Goble et al., 2021). One study did not specify which outcomes were assessed (Luzzato & Rusu, 2019).

3.2. *Characteristics of neuroscience-based professional learning programs*

The 15 studies investigated 13 distinct neuroscience-based professional learning programs. The *Tools of the Mind* program was evaluated in three studies (Diamond et al., 2019; Goble et al., 2021; Nesbitt & Farran, 2021). Of the 13 distinct training programs, all except one had a specific program name as shown in Table 3, which also displays abbreviated program names used in citations for this section. Most were offered as in-service professional development for practicing educators and two were offered only with pre-service educators (Diamond & Whittington, 2015; Luzzatto & Rusu, 2019).

The training programs employed a range of adult learning strategies such as online learning (e.g., *CD*, Anderson et al., 2020; *BDEY*,

Table 2
Characteristics of included studies.

Author, year, country	Research design, method, and participants	Professional learning *program name (abbreviation)* and duration	Approach	Focus
Anderson et al. (2020) USA	Uncontrolled pre- and post-test study (part of a larger longitudinal study) 293 children from 45 classrooms 31 pre-school teachers	*Conscious Discipline (CD)* Duration not reported	**Building knowledge** and **embedding specific practices**	Promoting emotional development and self-regulation in children
Archer & Siraj (2015) UK	Mixed methods non-equivalent groups quasi-experimental study, and interviews 4 early childhood centres, baby, toddler and preschool room leaders, practitioners, and managers (exact educator numbers not reported)	*Training in movement-play (TIMP)* 1 x full day course	**Building knowledge** and **embedding specific practices**	Physical movement and play for children
Cartmel et al. (2021) Australia	Realist evaluation, pre- and post-test, focus groups, and interviews N = 58 educators from four childcare centres and one kindergarten	*WINGS to Fly (Wings)* 12 h (2 x 6-h days or 6 x 2-h evenings)	**Building knowledge** and **embedding specific practices**	Promoting social and emotional development in children
Diamond et al. (2019) Canada	Cluster randomised controlled trial N = 352 children from nine kindergarten classrooms N = 9 kindergarten teachers	*Tools of the Mind (Tools)* Duration not reported	**Building knowledge** and **embedding specific practices**	Promoting social and emotional development in children
Diamond & Whitington (2015) Australia	Qualitative thematic analysis of students' written online discussion contributions and anonymous responses to a standardised course evaluation instrument N = 45 pre-service and in-service educators (predominantly preschool educators and undergraduate early childhood education students)	UniSA Elective Unit: *Brain development in the early years (BDEY)* 1 x semester course over 12 weeks	**Building knowledge**	Early childhood brain development
Goble et al. (2021) USA	3-arm randomised controlled trial (this study used data from one arm) N = 75 pre-school teachers from 104 Head Start centres	*Tools of the Mind (Tools)* Duration not reported	**Building knowledge** and **embedding specific practices**	Promoting children's executive function
Herman & Whitaker, 2020; Whitaker et al., 2019 [a] USA	Cluster randomised controlled trial with a mixed methods impact evaluation N = 96 early childhood teachers from 63 classrooms at 38 sites	*Enhancing Trauma Awareness (ETA)* 6 x sessions over 12-weeks	**Building knowledge**	Trauma-informed care
Howard-Jones et al. (2020) UK	Uncontrolled pre-post-test-follow up study N = 585 K-12 teachers who attended professional development	*Science of Learning (SoL)* 1 x 1.5-h session.	**Building knowledge**	Learning processes in children
Lang et al. (2020) USA	Pilot study, uncontrolled pre- and post-test N = 63 early childhood teachers	*Social Emotional Learning for Teachers (SELF-T)* 5 x 3-h self-paced online lessons over 2 weeks	**Building knowledge**	Stress reduction strategies for teachers
Lashinsky, 2019 USA	Mixed methods uncontrolled pre- and post-test study with focus groups N = 45 K-6 teachers	Unnamed professional development *(UPD)* 6 x 30-min sessions over four weeks	**Building knowledge**	Core concepts of neuroscience for teachers
Luzzatto & Rusu, 2019 Israel	Mixed methods uncontrolled pre- and post-test study with interviews. Pre-service teachers (N not reported)	*Neuroscience Teacher Based Teacher Training Program (NMTTP)* 10 x 90-min lessons over 1 year	**Building knowledge**	Core concepts of neuroscience and special education for teachers
Nesbitt & Farran (2021) USA	Cluster randomised controlled trial N = 877 pre-kindergarten children (mean age 54 months) N = 60 pre-kindergarten teachers (most females; average experience = 12 years; half with master's degrees; all had teaching assistant)	*Tools of the Mind (Tools)* Implemented as part of daily practice	**Building knowledge** and **embedding specific practices**	Promoting social and emotional development in children
Parr (2016) USA	Mixed methods, pre-post-follow-up and interviews N = 44 K-12 teachers from one public school district	*Brain-Targeted Teaching (BTT)* 1 x 6-h learning session	**Building knowledge**	Brain development and learning processes in children
Sexton et al. (2022) Australia	Feasibility study, pilot cluster-randomised-controlled trial N = 188 pre-school children from 6 early learning centres N = 25 early learning educators (24 female, 1 male)	*Early Minds (EM)U* 8-week, app-based educator-delivered, mindfulness-informed program [Program for children: 8 weeks, 3 activities per week]	**Building knowledge** and **delivering a structured intervention**	Mindfulness practices children

(*continued on next page*)

Table 2 (*continued*)

Author, year, country	Research design, method, and participants	Professional learning *program name (abbreviation)* and duration	Approach	Focus
Williams et al., 2023 [a] Williams et al. (2020) Australia	Cluster randomised controlled trial N = 213 children (mean age 50.54 months) N = 8 kindergarten teachers from 8 centres	*Rhythm and Movement for Self-Regulation (RAMSR)* Series of 4 session plans, with each plan to be repeated daily for 2 weeks	**Building knowledge** and **delivering a structured intervention**	Promoting rhythm and movement-based education for children

[a] Primary (index) studies are marked with an asterisk.

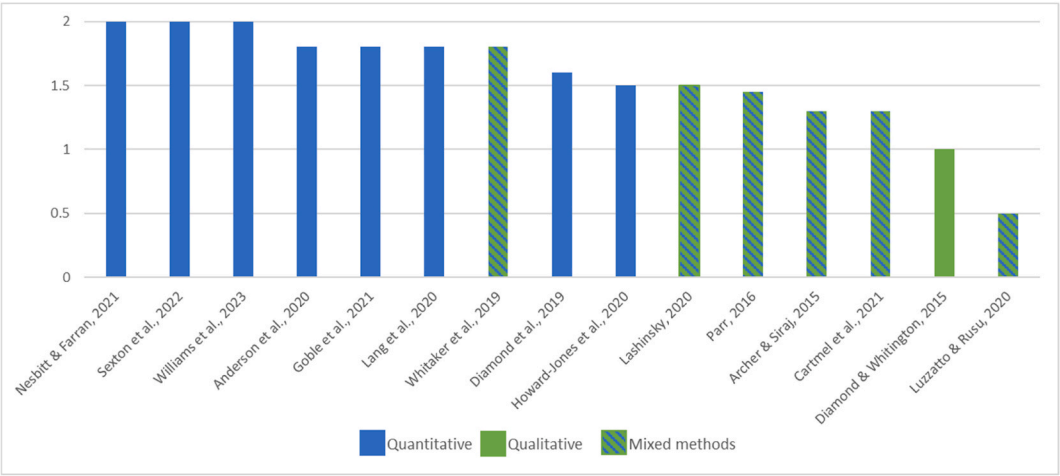

Fig. 2. Study quality assessment (n = 15) (Kmet, 2004).

Diamond & Whitington, 2015; *SELF-T*, Lang et al., 2020; *EM*, Sexton et al., 2022; *RAMSR*, Williams et al., 2023a), critical conversations (e.g., *Wings,* Cartmel et al., 2021), metacognitive-critical thinking (e.g., *NMTTP*, Luzzato & Rusu, 2019), discussion (e.g., *UPD*, Lashinsky, 2019; *NMTTP*, Luzzato & Rusu, 2019), mentoring and coaching (e.g., *Wings,* Cartmel et al., 2021; *Tools,* Nesbitt & Farran, 2021; *RAMSR*, Williams et al., 2023a), and active experiential learning (e.g., *Wings*, Cartmel et al., 2021; *BDEY*, Diamond & Whitington, 2015; *NMTTP,* Luzzato & Rusu, 2019).

Training duration differed widely from single sessions of 1.5–6 h duration (n = 3) (SoL, Howard-Jones et al., 2020; *BTT*, Parr, 2016; *TIMP*, Archer & Siraj, 2015) to multiple 30-min to 3-h sessions over periods of up to 12 weeks (n = 8) (*Wings*, Cartmel et al., 2021; *BDEY*, Diamond & Whitington, 2015; *ETA*, Whitaker et al., 2019; *SELF-T*, Lang et al., 2020; *UPD*, Lashinsky, 2019; *NMTTP*, Luzzatto & Rusu, 2020; *EM*, Sexton et al., 2022; *RAMSR*, Williams et al., 2023a). In one instance, *Tools of the Mind* training was offered over the course of an entire year incorporating intensive workshops and coaching support (Nesbitt & Farran, 2021) while, in two other instances, the training duration for this program was not reported (Diamond, 2019; Goble et al., 2021). Training duration was not reported for *Conscious Discipline* (Anderson et al., 2020).

We allocated one or more of our three previously detailed categories of approach to each paper, specifically: (i) those that focussed on *building knowledge* in educators, (ii) those that aimed to have educators *embed specific practices* in their work; and (iii) those that trained educators to *deliver a structured intervention* to children (see Table 2). Seven programs aimed solely to increase knowledge (*BDEY*, Diamond & Whitington, 2015; *ETA*, Whitaker et al., 2019; *SoL*, Howard-Jones et al., 2020; *SELF-T*, Lang et al., 2020; *UPD*, Lashinsky, 2019; *NTTP*, Luzzatto & Rusu, 2020; *BTT*, Parr, 2016). The focus of these programs was varied, including early childhood brain development and learning processes, trauma-informed care, stress-reduction strategies for teachers, and core concepts of neuroscience for teachers. Four programs aimed to both increase knowledge and teach educators to embed specific practices (*CM*, Anderson et al., 2020; *TIMP*, Archer & Siraj, 2015; *Wings*, Cartmel et al., 2021; *Tools*, Diamond et al., 2019; Goble et al., 2021; Nesbitt & Farran, 2021). The focus of these programs was less varied and included practice tools to enhance children's social and emotional development, self-regulation, and executive function, with one program focusing on physical movement and play (Archer & Siraj, 2015). Finally, two Australian programs were aimed at both building knowledge and training teachers to deliver specific interventions to children (*EM*, Sexton et al., 2022; *RAMSR*, Williams et al., 2023a). *Early Minds* is an app-based mindfulness-informed program delivered by teachers as three activities each week with children, over an eight-week period. *RAMSR* is a music-therapy informed program delivered by teachers as daily 15–20-min rhythmic movement sessions with children, over an eight-week period.

3.3. Evidence of effectiveness: educator and classroom level outcomes

Of the 15 included studies, 12 assessed educator-level outcomes, and two assessed classroom-level outcomes (Anderson et al., 2020;

Table 3
Findings summary.

Author, year, program name	Research design and approach	Educator and classroom level outcomes	Child outcomes	Implementation factors
Anderson et al. (2020) *Conscious Discipline (CD)*	Uncontrolled pre- and post-test study (part of a larger longitudinal study) **Building knowledge** and **embedding specific practices**	Fidelity significantly positively associated with higher overall **quality of teacher-child interactions** (CLASS scores)	Fidelity significantly positively associated with **children's executive function and social skills** in spring (5 months after initial assessment) [quantitative] No significant association between fidelity scores and children's basic academic skills	Implementing the program as it was originally intended by the program developers (fidelity) was significantly positively associated with higher scores in overall classroom quality.
Archer & Siraj (2015) *Training in movement-play (TIMP)*	Mixed methods non-equivalent groups quasi-experimental study, and interviews **Building knowledge** and **embedding specific practices**	Increase in the **variety and quality of classroom movement-play experiences**. One room showed increase in space and resources allocated for movement-play [quantitative & qualitative] Educators enjoyed their work more [qualitative]		Educators agreed or strongly agreed that the course had met their needs and they felt confident to implement what they had learned.
Cartmel et al. (2021) *WINGS to Fly (Wings)*	Realist evaluation, pre- and post-test, focus groups, and interviews **Building knowledge** and **embedding specific practices**	Increased **educator knowledge and confidence** in supporting children's emotional and social wellbeing [quantitative] Educator-reported changes in the areas of **communication, relationship building, and social and emotional wellness** [qualitative]		Training and resources provided to educators facilitating positive outcomes.
Diamond et al. (2019) *Tools of the Mind (Tools)*	Cluster randomised controlled trial **Building knowledge** and **embedding specific practices**	Significant increases in educators' estimations of children's ability to work on their own unsupervised, and **expectations for what children could accomplish** [quantitative] By the end of the school year, educators participating in the program **remained enthused** about teaching [quantitative]	Significant positive increases in children's reading, writing, (**academic outcomes**) No changes in math skills [quantitative] Significant positive increases in children's ability to get back to work after a break and ability to work independently (**executive functioning**) [quantitative] Significant positive decreases in children's trouble interacting with others (**sociability**) [quantitative]	Educators began with high levels of willingness to learn and implement the program, and this may have strengthened the program's effects
Diamond & Whitington (2015) Australia UniSA Elective Unit: *Brain development in the early years (BDEY)*	Qualitative thematic analysis of students' written online discussion contributions and anonymous responses to a standardised course evaluation instrument **Building knowledge**	Program had a positive impact on pre-service educators' thinking about professional practice and **the value or utility of learning about early brain development** [qualitative]		
Goble et al. (2021) *Tools of the Mind (Tools)*	3-arm randomised controlled trial (this study used data from one arm) **Building knowledge** and **embedding specific practices**		Significant positive effect for implementation fidelity on children's **executive function** gains as measured using Head-to-Toes. No effect for implementation fidelity on children's executive function gains as measured using Pencil Tap [quantitative]	Educators with less experience were more likely to make practice improvement gains resulting in greater growth in children's executive function skills Educators with higher levels of psychological distress showed higher levels of program fidelity No significant effects for training attendance or implementation quality on classroom gains in executive functioning [quantitative]

(*continued on next page*)

Table 3 (*continued*)

Author, year, program name	Research design and approach	Educator and classroom level outcomes	Child outcomes	Implementation factors
Herman & Whitaker, 2020; Whitaker et al., 2019 [a] *Enhancing Trauma Awareness (ETA)*	Cluster randomised controlled trial with a mixed methods impact evaluation	Teacher-child conflict scores were not significantly different for educators who had received the program and those who had not [quantitative] In focus groups, educators reported improvements in **teacher-children relationship** quality [qualitative]		Course implementation was undertaken with careful consideration for educators' feelings of safety to share personal experiences
Howard-Jones et al. (2020) *Science of Learning (SoL)*	Uncontrolled pre-post-test-follow up study **Building knowledge**	Immediately following professional development, educators **attributed higher value** to scientific concepts for understanding their practice and lower value to performative concepts [quantitative] Effects were only slightly eroded at follow up [quantitative]		
Lang et al. (2020) *Social Emotional Learning for Teachers (SELF-T)*	Pilot study, uncontrolled pre- and post-test **Building knowledge**	Educators demonstrated increased **knowledge** about stress, increased use of **emotional regulation strategies, increased personal stress**, [quantitative] Educators were more likely to **encourage children** to express negative emotions and less likely to dismiss or select punitive responses to children's social transgressions but more likely to react indifferently or select disciplinary responses to children's negative emotions [quantitative]		
Lashinsky, 2020 *Unnamed professional development (UPD)*	Mixed methods uncontrolled pre- and post-test study with focus groups **Building knowledge**	Educators increased **understanding** of neuro-literacy and common neuromyths [quantitative]		Educators reported that they do not routinely encounter information on neuro-literacy and common neuromyths. They may perceive it to be overwhelming and constantly changing
Luzzatto & Rusu, 2020 *Neuroscience Teacher Based Teacher Training Program (NMTTP)*	Mixed methods uncontrolled pre- and post-test study with interviews. **Building knowledge**	Preservice teachers developed positive **attitudes** towards neuroeducation and neuroeducation "motifs" were reflected in pre-service teachers' lesson plans [qualitative] self-efficacy regarding the use of neuroeducation concepts and attitudes towards neuroeducation [qualitative]		
Nesbitt & Farran (2021) *Tools of the Mind (Tools)*	Cluster randomised controlled trial **Building knowledge** and **embedding specific practices**		Null effects for all child-level outcomes: **academic achievement, executive function and self-regulation, teacher-rated classroom behaviours** [quantitative]	More experienced educators exhibited less implementation fidelity [quantitative and qualitative]
Parr (2016) *Brain-Targeted Teaching (BTT)*	Mixed methods uncontrolled pre-and post-test study with follow-up and interviews **Building knowledge**	Educators' **awareness and knowledge of** brain-based learning and brain-targeted teaching increased [quantitative] Educators **increased the use of BTT strategies** in their classrooms [qualitative & quantitative]	Educators reported increased **student engagement** [quantitative]	

(*continued on next page*)

Table 3 (*continued*)

Author, year, program name	Research design and approach	Educator and classroom level outcomes	Child outcomes	Implementation factors
Sexton et al. (2022) *Early Minds (EM)*	Feasibility study, pilot cluster-randomised-controlled trial **Building knowledge** and **delivering a structured intervention**		No difference between educator- and parent-reported outcomes for **children's social-emotional wellbeing and executive function** [quantitative]	Program did not meet feasibility requirements for implementation, practicality and adaption, and showed mixed results for acceptability and integration Parent-reported feasibility was not established because too few parents used the program Program requires modification to address educator needs and improve child suitability and engagement Following modification, re-assessment of feasibility is required
Williams et al., 2023 [a] Williams et al. (2020) *Rhythm and Movement for Self-Regulation (RAMSR)*	Cluster randomised controlled trial **Building knowledge** and **delivering a structured intervention**	Educator **knowledge** of self-regulation in early childhood, knowledge of music for brain development, **confidence** to use rhythm and movement, **frequency of use**, beliefs about music for children's development increased [quantitative]	Positive and significant effects for children's **teacher-reported self-regulation** [quantitative]. No significant effects for executive function, working memory, inhibition, self-regulation, school readiness, visual-motor coordination [quantitative].	Intervention fidelity was very high [quantitative]

[a] Primary (index) studies are marked with an asterisk.

Archer & Siraj, 2015). A variety of educator outcomes were measured including: knowledge and awareness (n = 5, Cartmel et al., 2021; Lang et al., 2020; Lashinsky, 2019; Parr, 2016; Williams et al., 2023a); attitudes towards neuroeducation (n = 3, Diamond & Whitington, 2015; Howard-Jones et al., 2020; Luzatto & Rusu, 2020); confidence and self-efficacy (n = 3, Cartmel et al., 2021; Luzatto & Rusu, 2020; Williams et al., 2023a); educator practices including relational capacities between educators and children (n = 6, Archer & Siraj, 2015; Cartmel et al., 2021; Diamond et al., 2019; Lang et al., 2020; Whitaker et al., 2019; Williams et al., 2023a); and educator wellbeing (n = 4, Archer & Siraj, 2015; Cartmel et al., 2021; Diamond et al., 2019; Lang et al., 2020).

3.3.1. Educator knowledge and awareness of neuroscience-based concepts

A total of five studies examined educator knowledge and/or awareness of neuroscience-based concepts as an outcome of the professional learning program. One RCT trained preschool educators to deliver a specific intervention to children, with training including information on self-regulation development in young children, and the role of music in brain development (Williams et al., 2023a). Four educators received the training and four did not, with survey measures related to educator knowledge completed pre and post. While the sample size was too small to understand the statistical significance of any differences, there was a trend for those educators in the intervention group to gain enhanced knowledge of self-regulation and music for brain development, compared to educators in the control group. In other studies educators also reported significant pre to post improvements following professional learning (ranging from 3 to 15 h in duration) in: knowledge about how to support children's emotional and social wellbeing (Cartmel; *Wings to Fly*); knowledge about stress (Lang et al., 2020; *Social emotional Learning for Teachers*); understanding of neuroliteracy and common neuromyths (Lashinsky, 2019); and awareness and knowledge of brain-based learning and brain-targeted teaching approaches (Parr, 2016; *Brain-Targeted Teaching*).

3.3.2. Attitudes towards neuroeducation

A total of three studies examined educators' attitudes toward neuroeducation. Two studies delivered professional learning to educators and used self-report surveys pre and post to examine attitudinal changes (Howard-Jones et al., 2020, Luzatto & Rusu, 2020). Howard-Jones et al. (2020) reported that immediately after a single 90-min session about learning processes in children (*Science of Learning*), K-12 educators attributed higher value to scientific concepts for understanding their practice, compared to their baseline scores. At follow up (6–12 weeks later), these attributions were only slightly eroded. Luzato and Rusu (2019) found more positive attitudes toward neuroeducation in pre-service teachers following ten x 90-min professional learning sessions over a one-year period (*Neuroscience Teacher Based Teacher Training Program*), compared to their baseline attitudes. In this study, qualitative analyses of pre-service teachers' lesson plans also uncovered increased neuroeducation motifs were present over time. While these are useful evaluations of these professional learning approaches, it is important to note that neither study included a control group or alternative comparison condition. Diamond and Whitington (2015) studied pre-service teachers' experience of a university elective unit called *Brain development in the early years*, studied over a 12-week period. Students' contributions to online discussion boards were analysed and findings suggested that students gained enhanced understanding of the value or utility of learning about early brain development.

3.3.3. Educator confidence and self-efficacy

Two studies reported findings on educator confidence and self-efficacy. Cartmel and colleagues' (2021) pre and post surveys with 58 childcare and preschool educators who completed 12 h of *Wings to Fly* training found a significant increase in educator confidence in supporting children's emotional and social wellbeing. Preschool teachers trained to deliver a specific rhythm-based intervention to children also reported increases pre to post in their confidence to use rhythm and movement (Williams et al., 2023a). Luzzato and Rusu (2019) proposed collection of educator self-efficacy data pre- and post-program, however findings were not reported in this paper (see our comment in relation to this study under 'Limitations' below).

3.3.4. Educator practice including relational capacities between educators and children

A total of six studies examined changes in educator practices associated with the professional learning program. An RCT study of the *Tools of the Mind* program found significant increases in educators' estimations of children's ability to work on their own unsupervised, and increased expectations for what children could accomplish in the intervention group (n = 16 teachers compared to the n = 15 control group) (Diamond et al., 2019). Training to deliver the *RAMSR* program, did increase educator-reported frequency of use of rhythm and movement in preschool classrooms in one RCT with a very small group of educators (n = 4 in the intervention group; Williams et al., 2023a). Similarly, specific training in movement-play was found to increase the variety and quality of classroom movement-play experiences (Archer & Siraj, 2015), and a brain-targeted teaching program with 44 K-12 teachers undertaking 6 h of professional learning, increased teachers' self-reported application of brain-targeted teaching strategies in their classrooms from pre-to post test.

In a pre-post study with 63 early childhood teachers undertaking 15 h of *Social Emotional Learning for Teachers* (Lang et al., 2020), pre-post educator reports on scales related to coping with children's negative emotions and challenging social interactions yielded significant results. Baseline to post-training scores significantly increased on two subscales indicating that educators were more likely to encourage children to express negative emotions and less likely to dismiss or select punitive responses to children's social transgressions. However, there was also an unexpected increase in educators' behaviours in reacting indifferently or selecting disciplinary responses to children's negative emotions. The authors suggested that additional training with more explicit case studies of how new knowledge and strategies can be implemented in the classroom was needed.

Two studies reported on findings from the implementation of *Enhancing Trauma Awareness* professional learning with 96 early childhood teachers. Although quantitative findings from the RCT did not show decreases in teacher-child conflict scores as hypothesised, qualitative data collected found teachers reported improvements in teacher-child relationships (Whitaker et al., 2019). Qualitative reports also indicated educators had changed their behaviour as a result of training in *Wings to Fly*, including increased positive practices associated with communicating and building relationships with very young children (Cartmel et al., 2021).

3.3.5. Educator wellbeing

In the *Tools of the Mind* RCT, quantitative self-reports of teacher enthusiasm for the following school year, showed that teachers in the intervention group were more likely to be enthusiastic and looking forward to the year, compared to the control group who had not trained in *Tools* (Diamond et al., 2019). Teachers who undertook *Social Emotional Learning for Teachers* (SELF-T) (Lang et al., 2020) reported an increased level of personal stress post intervention, despite reporting increased knowledge about stress and increased use of emotional regulation strategies. The authors suggest that this is because of the increased knowledge gained in terms of recognising signs of and being aware of their own stress levels, bring to conscious awareness level and severity of stress. In qualitative data, educators trained in *Wings to Fly* reported becoming more aware of the own social emotional wellbeing and how it impacted others (Cartmel et al., 2021), and those who had trained in movement play reported enjoyment in their work (Archer & Siraj, 2015).

3.4. Evidence of effectiveness: child outcomes

Three RCTs included in the review measured a range of social-emotional and academic outcomes for children. Mixed effects were reported for the *Tools of the Mind* program, though it is important to note that these two *Tools* studies were for different versions of the program. An earlier study with 352 children in Canada on the kindergarten version of *Tools* found positive impacts for children's reading, writing, ability to get back to work after a break and work independently, and a decrease in children's trouble interacting with others (Diamond et al., 2019). There was no impact on math skills. A more recent *Tools* RCT examined the prekindergarten version with 877 children in the United States and reported no effects for children's academic achievement, executive function, self-regulation, and classroom behaviours (Nesbitt & Farran, 2021). A specific rhythm and movement program (*RAMSR*) delivered by teachers in the year prior to school and studied in an RCT found significant pre to post improvements in children's self-regulation as reported by teachers, but no changes in executive function, school readiness or visual motor integration measures (Williams et al., 2023a).

3.5. Implementation factors

Implementation fidelity, that is implementing the program as intended by its developers, was examined in several studies with expected positive links reported between high levels of fidelity and positive outcomes for children (Anderson et al., 2020; Goble et al., 2021). Fidelity to the practices taught in professional learning was found to be an important fact in achieving higher overall quality of teacher-child interactions in 45 classrooms where teachers had trained in *Conscious Discipline* (Anderson et al., 2020). Interestingly, two studies that assessed the same program (though different version for different ages; *Tools of the Mind*) found that more experienced teachers were linked with lower implementation fidelity (Anderson et al., 2020; Goble et al., 2021). It is possible that more experienced

teachers felt more confident to adapt the program to their own context, yet this presents a challenge to researchers conducting RCTs. High levels of overall implementation fidelity were reported by Williams et al. (2023a) for the *RAMSR* program, but these were not linked in any way with the measured child outcomes.

A number of studies reported on aspects related to the perceived value or endorsement of the intervention. Educators reported high levels of willingness to learn (Diamond et al., 2019) and reported satisfaction and endorsement of professional learning provided (Archer & Siraj, 2015; Cartmel et al., 2021; Diamond & Whittington, 2015; Howard-Jones et al., 2020). Sexton et al. (2022) examined feasibility of the *Early Minds* program and found it did not meet requirements for practicality and adaptation and showed mixed results for acceptability and integration with the authors suggesting that program modifications are required to address educator needs and improve feasibility.

In terms of implementation enablers, Herman and Whitaker (2020) reported the need to take careful consideration of feelings of personal safety in their *Enhancing Trauma Awareness* program in which educators may share personal experiences. In relation to implementation barriers, time restraints and educators reportedly stopping implementation of new approaches once training and support cease were considered significant barriers to effectiveness (Nesbitt & Farran, 2021). One study also reported the limitation of embedding neuroscience-based content into an existing pre-service educator course where there was pressure to focus on the original and pre-existing curriculum for the course (Luzzato & Rusu, 2019). Further, information technology (IT) problems sometimes rendered online professional learning content inaccessible when needed (Sexton et al., 2022).

4. Discussion

This study aimed to scope literature on existing neuroscience-based professional learning programs for early childhood educators in the context of contemporary mandates for enhanced neuro-informed practices in the sector. What are the characteristics of neuroscience-based professional learning programs for ECEC educators and what approaches are taken? We identified a diverse array of programs designed to support children's brain development via upskilling the ECEC workforce with professional learning opportunities. The professional learning approaches aimed to do one or more of three things: enhance educator knowledge, build educators' strategy or practice toolkits, and deliver a specific neuro-informed intervention to children. What is the evidence of program effectiveness? On balance of existing evidence, professional learning programs such as these appear to yield promising effects for educators and downstream effects for children, with further research being highly warranted.

4.1. The emerging evidence base and a theory of change

Overall, the corpus of studies reviewed here represent an emerging evidence base for approaches to translating neuroscience to early childhood education and care through professional learning programs for educators. The methodological quality of the studies was overall adequate with 10 of the 15 studies scoring at least 1.5 out of a possible 2 on the Kmet (2004) critical appraisal index. Improvements in future study designs would include more robust designs including experimental and quasi-experimental approaches, and greater clarity and focus on specific measurable mechanisms of change and their indicators.

Fig. 3 shows a proposed theory of change for neuroscience-based professional learning programs for educators built on assumptions proposed in existing conceptual models and research literature documenting potential change mechanisms in early childhood

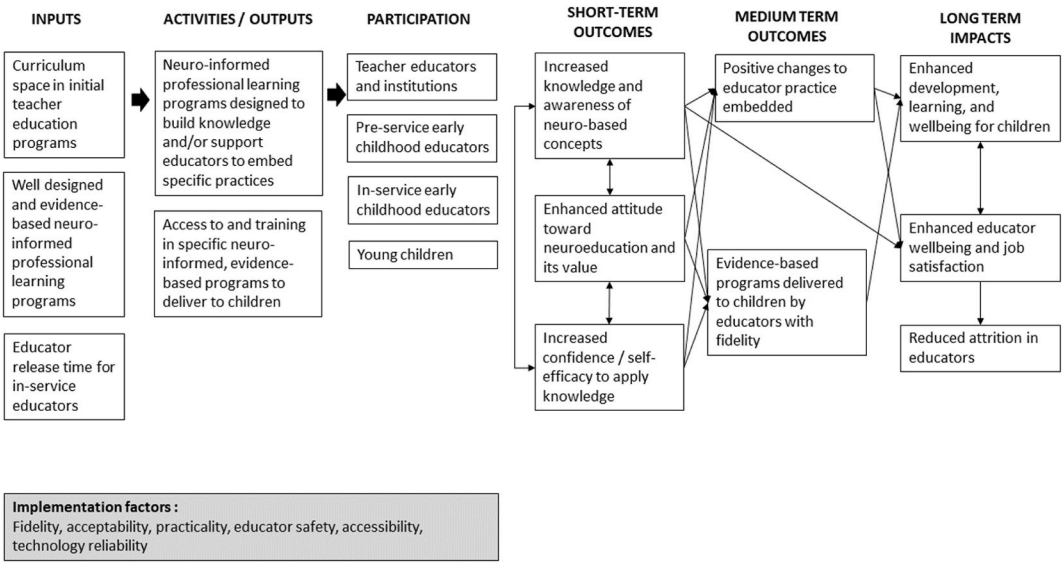

Fig. 3. Proposed theory of change for neuro-informed professional learning programs for educators.

education settings broadly (Blewitt et al., 2020; Brunsek et al., 2020), and the findings of the current review. These programs, regardless of their approach, aim to elevate educator knowledge and attitudes, in turn enhancing educator behaviour and practice, ultimately resulting in improved outcomes for both educators and children. Several studies documented the boosting of educator knowledge, attitudes, awareness, confidence, and self-efficacy regarding neuroscience, however none of these studies used a robust experimental design complete with comparison group, thus capacity to determine the extent to which the program was responsible for the reported was limited. The research designs in the study corpus thus limit the strength of this body of evidence. There was also some evidence that educators' practice and their own wellbeing was enhanced through some but not all approaches. Only three studies investigated downstream child outcomes, all using a robust RCT design. These were *Tools of the Mind* with positive findings for the kindergarten version (Diamond et al., 2019), and largely null findings for the pre-kindergarten version (Nesbitt & Farran, 2021), and the more recently developed *Rhythm and Movement for Self-Regulation (RAMSR*) program, with some positive findings for children's self-regulation skills (Williams et al., 2023a).

The fact that most included studies assessed outcomes at the educator level – predominantly focusing on knowledge and awareness of neuroscience-based concepts and to a lesser extent, attitudes towards neuroeducation, confidence and self-efficacy – with only three studies investigating child outcomes, largely reflects the maturity of the field and the types of programs studied. Specifically, it is appropriate to focus on more proximal and immediate impacts in the hypothesised theory of change (e.g., increased educator knowledge and awareness) early in the development of an evidence base. However, if the ultimate aim of neuro-informed professional learning for educators is to positively impact children's learning and development, future more sophisticated studies must investigate these more distal outcomes at both the child and educator level. For example, do initial boosts in knowledge, awareness, and confidence translate to changes in educator practice, even if specific practices were not taught as part of the professional learning? It is also important to track outcomes longitudinally over time. For example, are early gains in educator knowledge, attitudes, self-efficacy, and practice changes sustained over time, or do these fade away?

In terms of downstream outcomes, further research that builds an evidence base for the impact of neuro-informed professional learning on educator wellbeing and job satisfaction is essential. Given current workforce shortages, high levels of stress and attrition (Thorpe et al., 2020), this mechanism for change could be better leveraged in future. For example, do educators who know more about how their own brain works – as well as children's brains – have more success in manage their stress and workloads? Are they more satisfied in their workplaces? And are they retained in the field for longer?

Very few studies examined implementation factors for the approaches investigated. In studies in which these were examined, there was a strong and appropriate focus on implementation fidelity, or the extent to which educators delivered practices with children as intended from the professional learning. Overall, interventions yielded better outcomes when educators had delivered the activities with high fidelity, rather than when they had innovated, adapted, or tailored their delivery. Implementation fidelity is a recognised challenge as evidence-based approaches are scaled up beyond initial research conditions (Combs et al., 2022). Educators are trained to be innovators and problem-solvers, and with this comes motivation – intentionally or automatically – to adapt approaches to suit their context. While some contextual adaptations may be appropriate in some programs, the challenge for program developers is to clearly prescribe what can and cannot be adapted and to provide the learning and support required for high fidelity implementation across a range of contexts and over time. Further work is needed to better understand not only fidelity and supporting such, but the other implementation enablers and barriers in this field of work. This will inform designs for future approaches and scaling up of existing approaches.

The question remains regarding whether different approaches identified in this scoping review differ in effects and whether lessons can be drawn from these to advance separate theories of change. The issue of effectiveness of different approaches requires investigation in future reviews. However, before this is possible, the field requires more rigorous primary studies to be conducted and published on a range of programs and, in due course, for quantitative synthesis including sensitivity analyses in future meta-analyses to strengthen the evidence base.

4.2. Limitations

This scoping review has limitations for consideration. Our search strategy may have failed to identify studies that should have been included. For example, we were made aware of a study report relating to the included study by Luzzatto and Rusu (2019) that was published in 2019 and was arguably the index study, however it was not identified in any of our database or other searches. As explained in the method section, we restricted searches to what we considered to be the most relevant databases and did not contact authors of included studies to supply further information. In terms of search strategy, ideally a combination of subject heading and keyword searching is considered most effective, however subject headings can be unique to databases and of the databases we searched only PubMed enabled subject heading searches. Further, we restricted our search to studies published in English, which risks representing an incomplete view internationally of the work in this field. We excluded studies that reported only on child outcomes with no data related to educator outcomes. Therefore, the findings on effectiveness for child outcomes should be interpreted with caution, as they may not be representative of all neuro-informed programs that target children's brain development. Although the quality of the included studies was overall adequate, confidence in future study findings will be enhanced with more rigorous evaluation study designs based on theory of change and measurable outcomes.

4.3. Gaps and future directions for the field

Our scoping review identified a very limited number of approaches in pre-service educator programs, compared to in-service

approaches. This may be a reflection of the paucity of neuro-informed work with pre-service educators, or limited research and publication of this work. A desktop review of Australian pre-service education courses conducted in parallel with this review suggested the former applies, at least in the Australian domestic context, with very limited neuro-informed curriculum content found across accredited early childhood courses (Williams et al., 2023b). Given that recent reviews on teacher preparation programs stress the need for educators to have sound knowledge of the science of learning and brain development (Australian Government Department of Education, 2022b), this is an area requiring further implementation of neuro-informed approaches, and research on their effectiveness. Future reviews may also seek to identify and characterise neuroscience based professional learning programs for educators in primary (elementary) and secondary (high) schools.

This review opens an opportunity to design, implement, and evaluate an overarching coordinated evidence-based approach for translating neuroscience to early childhood education in professional learning programs for early childhood educators. In this review we categorised studies and identified three approaches: (i) building knowledge, (ii) embedding specific practices, and (iii) delivering a specific intervention to children. Across the included studies it was common for professional learning programs to combine two of these approaches (e.g. building knowledge, and delivering a specific intervention), but never all three. Could a more comprehensive approach to developing a neuro-informed education workforce include elements of all three approaches? What combination of approaches in professional learning across educators' careers could incrementally develop stronger knowledge, attitudes, self-efficacy, and practices from pre-service education through post qualification to in-service professional learning?

Further, as part of a more comprehensive strategy to use neuro-informed approaches to ultimately support child learning, development, and wellbeing, the role of parents must be considered. Programs aiming to uplift the same neuro-literacy, self-efficacy and changes in behaviour in parents were out-of-scope for the current review but are an important consideration for the field as a whole. Many children do not engage in formal early childhood education and care, and even for those that do, the parental context is still the most highly influential caring environment in terms of children's developmental trajectories. Indeed, extending neuro-informed capability building not only to parents but to non-education professionals that interact with young children and families is also a critical consideration as part of a comprehensive approach.

Finally, the nature of neuroscience is that it will be constantly updated and changing as neuroscientists discover more about the human brain. As part of a comprehensive approach, mechanisms for updating professional learning programs must be in place, and ideally professional learning should be designed in a multi-disciplinary setting involving neuroscientists and teacher educators. Educators also need support to select and engage in approaches that are evidence-based and regularly updated. Important to note, is that we did not undertake any quality assessment of the *content* of the neuro-based professional learning programs that were the subject of the studies presented here. It was beyond the scope of this study to evaluate the extent to which the content of the programs was of high quality in relation to the neuroscience evidence base, and its applicability to education. A growing body of work highlights the proliferation of neuromyths within education, that is misconceptions about the brain that are incorrect, incomplete or have been inappropriately extrapolated from valid neuroscience (Torrijos-Muelas et al., 2021). It is vital that professional learning for educators informed by neuroscience, does not act to proliferate neuromyths, but rather maintains a strict focus on the contemporary neuroscience evidence.

5. Conclusion

As international priorities focus on addressing positive early childhood development as critical to lifelong achievement and wellbeing, interest in translation of neuroscience to early childhood education is also elevated. Appropriate translation of neuroscience-based concepts to early childhood education requires high quality professional learning approaches that deliver the benefits desired. This scoping review has identified a range of approaches documented that variously aim to increase educator knowledge, support educators to embed specific practices, and/or deliver a highly structured intervention to children. The reported results suggest there is an emerging evidence base for this field of work, but more must be done to systematically articulate and study mechanisms of change from educator knowledge and attitude, through the expected developmental benefits accruing for children. Along with more robust studies, there is opportunity to better design a comprehensive approach to neuro-education for early childhood educators across both pre-service and post service career periods.

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Declaration of competing interest

Kate E Williams declares that she was the lead investigator and author of a study included in this review (Williams et al., 2020, 2023a). To minimise potential risk of bias, Dr Williams did not participate in study screening, selection, or data extraction.

Data availability

No data was used for the research described in the article.

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