CHAPTER 5

An Integrative Review of Cognitive Science and Neuroscience Findings about Mathematics Learning 2021–2023 – Time Lag in the Australian Context

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Abstract

Time-lag in curriculum can be described as a misalignment between the curriculum content that children are learning in schools and new and current research findings and developments. Addressing time lag as an issue for curriculum development is a significant challenge facing governments in numerous countries from around the world, particularly in relation to the current explosion of new technologies and the advancements in knowledge that this explosion has afforded. In this chapter we explore the issue of time-lag in the Australian context by analysing new developments in cognitive science and neuroscience about mathematics learning. We draw on integrative literature review as a methodology to assess, critique, and synthesise the literature in the cognitive sciences and neuroscience over the past three years. We then draw on this review to examine if time-lag is an issue for mathematics in the curriculum and highlight any implications on current teaching practice and mathematical learning. We conclude the chapter by introducing a new perspective that can be drawn on by policymakers to ensure that new and current research developments filter directly through to curriculum, teachers, and children in more timely and impactful ways.

Keywords

cognitive sciences – neuroscience – mathematics – mathematics education – time-lag in curriculum

1 Introduction

Over the past few decades advancements in technology have expanded and progressed new understandings about human learning. These advancements have also contributed to and shaped curriculum architecture, and have developed and nurtured the understandings, skills, and capacities of classroom teachers

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globally. The COVID-19 pandemic not only accelerated this advancement in technology, but it also highlighted and amplified the equity gaps within education, including the social, political, and economic implications of these gaps for different societies from around the world (Organisation for Economic Co-operation and Development (OECD), 2020). To address such inequity and to ensure that all children are adequately prepared for a future world, now more than ever before, it is imperative that curriculum transforms *alongside* the new research that technological advancement affords, rather than lags, which has historically been the case around the globe (McDiarmid et al., 2022). For the purpose of the research presented in this chapter, we refer to this 'lagging' and 'lagging behind' as time-lag in curriculum and we define it as the delay in time that it takes for the new knowledge required to progress humanity to be embedded in curriculum content and enacted in schools and other educational contexts.

An effective curriculum both responds to changes in society as well as addresses societal needs, existing and future societal challenges, and shifting beliefs and values. According to Wrigley (2014), it is also important to recognise that "any curriculum is unavoidably a selection from the totality of knowledge, and that the process of selection is underpinned by political ideology" (Wrigley, 2014, p. 15). Until recently, governments had time to consider what might be selected from the totality of knowledge for curriculum development. However, the rapid rate at which knowledge is now changing due to technological advancement, makes this selection more difficult to achieve. Particularly when we think about what might be required in relation to relevancy and what might be needed for future society and generations.

Historically, mathematics has and will continue to be a key component of future knowledge (Skovsmose, 2023). In fact, from its conception, human advancement of the knowledge of mathematics has been dependent on different technologies e.g. sticks, pebbles, pens, etc. Similarly, technologies, technological problems and technological advancement have been solved and developed with mathematics and mathematical tools (Hansson, 2020). As technology continues to infiltrate the day-to-day life of humankind, future knowledge will become more dependent on mathematics and mathematical tools (Yolcu & Kirchgasler, 2024). Understanding new advancements in mathematics and in how mathematics can be best learned (and taught) will become more important than ever before (Engelbrecht, et al., 2023).

Cultivating mathematical ability is the key driver of mathematics education and the main purpose of mathematics curriculum (Campbell, 2023). Therefore, understanding inherited biological predispositions for mathematics alongside new developments about the brain and learning, and culturally and contextually derived mathematics, has the potential to enhance mathematics education in ways that are yet to be experienced. However, unless the current lag in the mathematics curriculum is addressed and new ways to eliminate curriculum lag are developed, this experience might not ever be harnessed.

In this chapter we highlight the significant issue of time-lag in the Australian context by analysing new developments in neuroscience about mathematics learning. We draw on integrative literature review as a methodology to assess, critique, and synthesise the literature in mathematics-neuroscience over the past three years. We then draw on this review to examine time-lag in the current Australian Mathematics Curriculum and highlight the implications of this time-lag on current teaching practice and mathematical learning. We conclude the chapter by introducing a framework that can be drawn on by policymakers to ensure that new and current research developments filter directly through to curriculum, teachers, and children in more timely and impactful ways.

1.1 *Integrative Literature Review as Methodology*

When drawn on as a methodology, the aim of the integrative literature review is to "assess, critique, and synthesize the literature on a research topic in a way that enables new theoretical frameworks and perspectives to emerge" (Snyder, 2019, p. 335). The purpose is to "combine perspectives and insights from different fields or research traditions" as well as "create initial or preliminary conceptualizations and [or] theoretical models" (Snyder, 2019, p. 336). Drawing on an integrative literature review as a methodology involves advancing knowledge and developing theory, so the review is focused and purposeful (Snyder, 2019; Cronin & George, 2023).

The data analysis component of an integrative literature review is not prescriptive or developed according to a specific standard (Snyder, 2019). It is a critical analysis of the literature according to an issue or a question. In this chapter, the analysis has three phases. Phase one is focused on research question one, *what has been discovered about teaching and learning mathematics through the cognitive sciences and neuroscience over the past three years*. Phase two is focused on question two and explores whether the current mathematics curriculum reflects these advancements. Phase three draws on the answers to these two questions to develop a framework that can be drawn on by policymakers to ensure that new and current research developments filter directly through to curriculum, teachers, and children in more timely and impactful ways.

2 The Integrative Literature Review

2.1 *Phase 1*

There were two key research questions underpinning the integrative literature review:

1. What has been discovered about teaching and learning mathematics through the cognitive sciences and neuroscience over the past three years (2021–2022–2023); and
2. How is it being filtered into the curriculum?

The aim of this phase of the integrative review was to review literature from the cognitive sciences and neuroscience in relation to mathematics teaching and learning over the past three years. The review of research literature was broken into two stages. Stage one involved an explicit focus on neuroscience and cognitive science databases. The purpose of focusing explicitly on these databases was to establish what new studies in cognitive science and neuroscience about mathematics learning had been published in the past three years. It should be noted that although the focus of the study was on curriculum lag in the Australian context that the literature search was not restricted to research conducted in Australia.

The second stage of the review of research literature involved drawing on the PRISMA model to organise the literature. The PRISMA model (Page et al., 2020) provided an evidence-based minimum set of items to conduct the search for literature. Although generally used in systematic literature reviews the PRISMA model provided a concise way to focus the search and provision for consistency across the three-year timeframe that was being investigated. The difference between this integrative review and the systematic reviews usually conducted with the PRISMA model lies in the synthesis or integration of the literature to generate theory and new knowledge, rather than the description of the literature which is generally the purpose of the systematic review. In the study presented in this chapter the integrative review was driven by the two research questions and was structured around the purpose of answering the research questions. This information was then used to offer new perspectives about current research and the best ways to filter new research findings into the curriculum and classroom. In the following section this process is outlined.

3 Research Methods

3.1 *Information Sources*

There were four key databases identified that crossed over both neuroscience and cognitive science: MEDLINE (PubMed); Psychology and Behavioural Sciences Collection; PsycINFO; and Web of Science. The databases were searched across the three-year period *2021–2022–2023.*

3.2 *Search Strategy and Eligibility Criteria*

There were four key terms drawn on to search all databases. These terms were: *brain* and *mathematics* and *cognition* and *learning.* The first search resulted in a total of *n = 224* across all databases within the specified timeframe (2021–2023): *MEDLINE n = 15*; *PsycINFO n = 72*; *Psychology and Behavioural Sciences Collection n = 13*; *Web of Science n = 124.* An initial screening of abstracts and titles was made to ensure that articles were focused on children, the brain/cognition and mathematics learning. This screening was achieved through the removal of duplicate articles followed by a quick screen of paper title and abstract and the removal of any articles that did not fit within the scope of the four key areas of *brain* and *mathematics* and *cognition* and *learning*. After this initial screening a total of *n = 131* articles were identified *MEDLINE n = 14; n = Web of Science n = 62; PsychINFO n = 42; Psychology and Behavioral Sciences Collection n = 13.*

The inclusion and exclusion criteria were then applied to the search results and articles that did not fall within the criteria were removed. There were three inclusion criteria applied = *Focused on children; focused on mathematics learning; brain/cognitive-based investigations.* There were four exclusion criteria applied: *disability focused; focused on adults and children; focused on adults; studies with a third variable introduced* (*e.g. physical activity, machine learning etc.*). A second scan for duplicates was again performed at full text, the final number of studies included in the integrated synthesis were n = 18. *Figure 5.1* represents the review process.

3.3 *The Integrated Review of Literature*

The purpose of the integrative review methodology drawn on in this study had three key objectives, the first was to present a critical review, synthesis and integration of the knowledge base over the three-year review period, the second was to draw on the integrative review to establish how the latest research about teaching and learning through the cognitive sciences and neuroscience is being filtered into the current curriculum. The third was to use these findings to offer new perspectives on how curriculum lag might be addressed in the Australian context (and beyond). The literature that informs this integrative review is highlighted in Table 5.1.

4 Integrative Review Addressing Research Questions

> What has been discovered about teaching and learning mathematics through the cognitive sciences and neuroscience over the past three years (2021–2022–2023)?

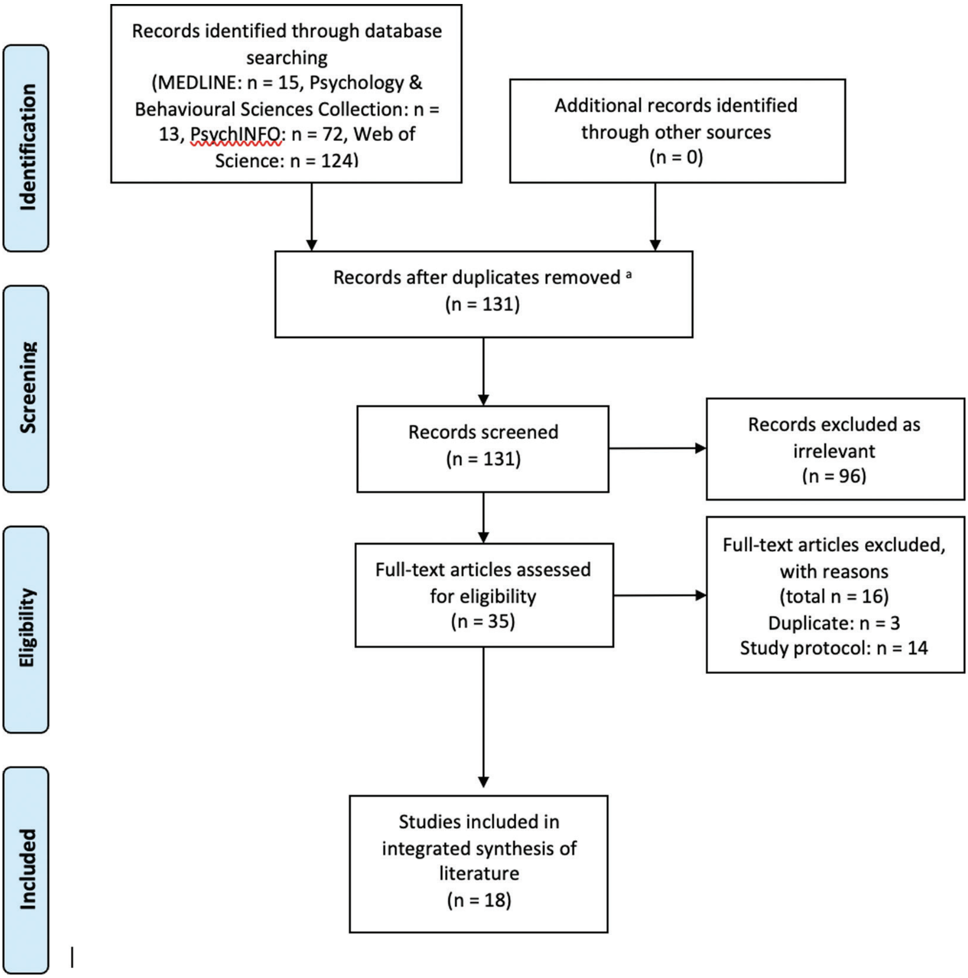

FIGURE 5.1 The Review Process – adapted from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal. pmed1000097

Numerical cognition is the dominant feature of the reviewed knowledge base. This is not surprising given the abundance of empirical data that highlights numerical cognition as a central and universally shared cognitive capacity that emerges early in human development (Barrouillet, 2018). Over the review period however, it appears that neuroscience has opened various avenues for identifying and isolating the core neural building blocks that scaffold and support numerical cognition. These neural building blocks and neurological connectivity patterns include insight into declarative and working memory as well as the representation of symbolic and non-symbolic numerical quantities. How these findings translate into supporting or improving learning, however, remains elusive within the research reviewed.

TABLE 5.1 Summary of literature reviewed

Publication type	Authors	Article title
Journal	Hawes, Z; Merkley, R; Stager, CL; Ansari, D	Integrating numerical cognition research and mathematics education to strengthen the teaching and learning of early number
Journal	Tay, LY; Chan, ML; Chong, SK; Tan, JY; Aiyoob, TB	Learning of Mathematics: A Metacognitive Experiences Perspective
Journal	Hyde, DIC	The Emergence of a Brain Network for Numerical Thinking
Journal	Anobile, G; Morrone, MC; Ricci, D; Gallini, F; Merusi, I; Tinelli, F	Typical Crossmodal Numerosity Perception in Preterm Newborns
Journal	Cheng, C; Kibbe, MM	Is Nonsymbolic Arithmetic Truly Arithmetic? Examining the Computational Capacity of the Approximate Number System in Young Children
Journal	Guerrero, D; Park, J	Arithmetic thinking as the basis of children's generative number concepts
Journal	Zhang, TY; Fyfe, ER	High variability in learning materials benefits children's pattern practice
Journal	Ren, BQ; Liang, XT; Li, JY; Cao, LY; Zhou, XL	A study on whether nonverbal inductive reasoning predicts mathematical performance
Journal	Kalyuga, S	Evolutionary Perspective on Human Cognitive Architecture in Cognitive Load Theory: a Dynamic, Emerging Principle Approach
Journal	Fang, SJ; Zhou, XL	Form perception speed is critical for the relationship between non-verbal number sense and arithmetic fluency
Journal	Hanham, J; Castro-Alonso, JC; Chen, OH	Integrating cognitive load theory with other theories, within and beyond educational psychology
Journal	Reigosa-Crespo, V; Estevez-Perez, N.	Conceptual foundations of early numeracy: Evidence from infant brain data
Journal	Anzalone, C; Luedke, J; Green, J; Decker, S.	QEEG coherence patterns related to mathematics ability in children.
Journal	Visibelli, E; Vigna, G; Nascrimber, C; Benavides-Varela, S.	Neurobiology of numerical learning.
Journal	Nieder, A.	Neural constraints on human number concepts
Journal	Chen, C; Liu, P; Li, S; Zhang, C; Zhou, X.	Visual but not visual-spatial working memory contributes to complex arithmetic calculation
Journal	Cheng, D; Cui, z; Hu, Y; Zhou, X.	Which visual property correlates with the relationship between numerosity sense and arithmetic fluency
Journal	Menon, V; Chang, H.	Emerging neurodevelopmental perspectives on mathematical learning

There appears to be a shared consensus across the literature identified that numerical competence is a phylogenetically primary aptitude that is shared and can be nurtured across human and non-human species (Anobile, 2021; Hyde, 2021; Guerrero & Park, 2023; Visibelli et al., 2024). There is also a consensus across most of the literature reviewed that an evolutionary foundation of basic numerical skills, that are shared between adults and young infants, exists (Anobile, 2021; Hyde, 2021; Guerrero & Park, 2023; Visibelli et al., 2024). In fact, neuroimaging studies have repeatedly demonstrated that "response to numerical transformations is biologically rooted, preserved in ontogeny, and already functional prior to symbolic education in humans" (Visibelli et al., 2024, p. 2). Again, however, insight into how this biologically rooted aptitude can be harnessed as a foundation to support further numerical competence and foster wider mathematics learning is missing across the data set.

It is not surprising that the evolutionary perspective on the architecture of numerical cognition has resulted in a predominant focus of research situated in the early stages of life development and on young children (Anobile, et al., 2021; Hawes, et al., 2021), with only a scattering of the research reviewed targeting school-aged children (Cheng & Kibbe, 2023; Tay et al., 2023; Ren et al., 2023; Fang & Zhou, 2022; Anzalone, et al., 2021; Chen et al., 2023; Cheng et al., 2022). Given that the cognitive sciences and neuroscience reasoning has been a prominent feature within early childhood and early childhood developments since the early sixties in Australia (Millei & Joronen, 2016), this is a curious discovery that may suggest an immaturity in the field in relation to progress and insights into mathematics-focused learning. The lack of emphasis on other areas of mathematics and the heavy focus on numerical cognition over the past three years would suggest that despite being a prominent feature of child development since 1960, that in relation to mathematics learning, this is still an emerging field of research.

Hawes and colleagues appear to be an exception in relation to operationalising their research and injecting it into the early year's context (Hawes, et al., 2021). Their researched spanned across the early years and school-based contexts and targeted teachers who were working with children within these contexts. The purpose of their work was to use cognitively guided instruction to educate teachers on the latest research findings on children's mathematical thinking and to teach them how to use this knowledge as a basis for assessment and instruction (Hawes et al., 2021). While the model was deemed a successful way to directly filter research into the hands of practitioners, the authors suggest that more work is needed in this area.

As was foreseeable, working memory and its role in numerical learning, number sense, arithmetic ability and numerical thinking featured widely across the articles. Interestingly, a focus on cognitive load theory coincided with a focus on the learning of older school-aged children (*see* Hanham et al., 2023). Across the articles examined there appears to be a gap in the research base around cognitive load and how this might apply to younger children. This was an interesting finding given the predominant focus and vast array of research situated in the early stages of life development and on young children. This gap could be attributed to widespread perceptions of young children and their capacity (or lack of capacity) to engage in sophisticated mathematics learning, it may be tied to the difficulties associated with research access to very young children or simply due to the selection of articles reviewed. Understanding more about cognitive load theory and how it might or might not be relevant in the years before formal schooling would provide some greater understanding of its role in future mathematics learning. Hanham and colleagues suggest that looking within *and* beyond the cognitive and neurosciences literature might be necessary to gain such understanding and insight (Hanham et al., 2023). In the following section we centre the integrative review more explicitly on curriculum. It should be noted that each context (the prior to school and formal schooling context) is guided by a different curriculum document. For the ease of this review, we integrate the literature with the two curriculum documents separately.

> How is the latest research about teaching and learning through the cognitive sciences and neuroscience being filtered into the curriculum?

Within the Australian context the policy document Belonging, Being and Becoming: The Early Years Learning Framework for Australia (V2.0) (EYLF) "may complement or supplement individual state or territory frameworks" (Australian Government Department of Education [AGDE], 2022, p. 5). The EYLF is designed for children's learning, development and wellbeing from birth to five years and through the transitions to school. Therefore, it is purported as being designed to be representative of the latest curriculum intentions for the development of mathematics and specifically the latest research findings about learning.

The EYLF contributes to Goal 1 and 2 of the Alice Springs (Mparntwe) Education Declaration:

> The Australian education system promotes excellence and equity.
> All young Australians become:
> confident and creative individuals
> successful lifelong learners
> active and informed members of the community.
> (Education Council, 2019, p. 4)

To understand the latest research in this area it is vital that consideration is given to the perspective of cognitive science and neuroscience that has underpinned the Australian early childhood context in Australia for the past eighty-plus years (Millei & Joronen, 2016). According to the American Psychological Association (APA), cognition is defined as "all forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving. Along with affect [emotion] and conation [motivation], it is one of the three traditionally identified components of mind" (American Psychological Association, 2019). Cognitive science sits within the broader field of psychology and education. The modern cognitive perspective "is in part a reaction to behaviourism and in part a return to the cognitive roots of psychology. Like the nineteenth-century version, the modern study of cognition is concerned with mental processes, such as perceiving, remembering, reasoning, deciding, and problem solving" (Atkinson et al., 1990, p. 11). Differing to behaviourists, cognitive psychologists believe that your behavior is determined by your expectations and emotions. Cognitive psychologist Jean Piaget would argue that you remember things based on what you already know. You also solve problems based on your memory of past experiences.

Within neuroscience it is recognised that while the physical body slows down as it ages, brain connections (plasticity) improve as one grows and develops (Greenfield, 2012). When it comes to the teaching and learning of mathematics for all ages. There are arguments based on research into how humans best learn that explicit instruction is the preferred pedagogical approach. "We should be teaching domain-specific knowledge, not generic skills" and "Initial instruction when dealing with new information should be explicit and direct" (Australian Government, 2014, p. 125). For the example of acquiring basic mathematical skills, "the research clearly shows that teacher-directed learning is better suited. Needless to say, these basic skills must be firmly in place before students can approach problem-solving questions with any degree of competence" (2014, p. 126).

However, during the Australian Early Years curriculum reform review, it was recommended that teachers use an eclectic choice of approaches to best suit their context (Australian Government, 2014) which was also supported by Ornstein and Hunkins (2017) and advocated by Lynch (2014, 2019)

Hence, the purpose of education is to achieve all approaches:

1. Develop practical skills, strengthen productivity (utilitarian).
2. Prepare and deal with the future (twenty-first century learning).
3. Develop the child (personalised learning).
4. Critique society (equity and social justice).
5. Introduce students to the best that has been thought and said (enculturation) (Australian Government, 2014, p. 24).

All approaches have a place and evidence-based research suggests that there should not be a prevalence of certain approaches (and pedagogies embedded within) over others.

Within the early years' context, it is essential then that the latest findings in cognitive sciences and neuroscience are tailored and developmentally appropriate for the age of children, birth to five, and therefore the latest findings in holistic education must be considered. It is acknowledged that "children's learning is dynamic, complex and holistic" (AGDE, 2022, p. 8) and more so, argued that the physical dimension is significant within children's learning because it offers powerful and meaningful connections across all learning and development areas (Lynch, 2019). The socio-cultural perspective suggests that the curriculum ought to be connected to the child's world and everyday interests (Arthur et al., 2020). Since children have a natural play structure, learning through movement heightens their interest.

During the birth to five years period of development, play-based learning enables the culmination of the various educational and cognitive-based approaches at a developmentally appropriate level play-based learning capitalises children's natural interest and wonder to explore and be curious. In play experiences children integrate their emotions, thinking and motivation that assists to strengthen brain functioning. They exercise their agency, intentionality, capacity to initiate and lead learning, and their right to participate in decisions that affect them, including about their learning (AGDE, 2022, p. 8).

Play-based learning involves learning through movement. Research suggests that learning through movement promotes mental and social wellbeing, and can improve cognitive memory (Zhu et al., 2014). Toddlers and preschoolers are recommended at least three hours of physical activity per day and children in the 5–12 years age group are recommended 60 minutes a day of moderate-to vigorous-intensity physical activity for social, emotional, intellectual and health benefits (Commonwealth of Australia, 2014). Lynch (2024) specifically advocates learning mathematical concepts through movement and play.

Despite the emphasis on play-based learning and the well-established understanding of the physicality of learning mathematics in the years before formal schooling, that is a prominent feature of the Early Years Learning Framework for Australia (V2.0), in relation to the research base that was reviewed for this chapter play-based learning and physicality were not vehicles drawn on in any of the studies. In fact, much of the research reviewed, that was situated in the years before formal schooling, did not incorporate any mention of play or physicality in the study presented.

Despite the omission of play and physicality it is evident that the ideas presented in the research reviewed does have a presence in the Early Years

Learning Framework for Australia (V2.0). Mathematics and numeracy in the curriculum are defined as:

> broadly includ[ing] understandings about numbers, patterns, measurement, time, spatial awareness and chance, and data, as well as mathematical thinking, reasoning and counting. (ADGE, 2022)

The research reviewed that was situated in the early years' context was primarily focused on numerical cognition (Anobile, et al., 2021; Hyde, 2021; Guerrero & Park, 2023; Visibelli et al., 2024). This appears to be an underpinning driver of the definition of mathematics and numeracy provided. It is also evident in the wider curriculum document which states that "All children bring new mathematical understandings through engaging with problem solving" and that "[t]o build their numeracy, children explore powerful mathematic ideas in their world … along with drawing connections and argumentation" (ADGE, 2022, p. 57). In the following section we examine the formal schooling curriculum document which spans across primary and secondary school contexts.

The school-based context provides a more-structured context for cognitive and neuroscience researchers to apply and test some of their findings. Whilst only 40% of the literature reviewed in this study was situated in school-based contexts, this was the literature that provided the most direct and explicit insight into how findings might be used to support children's mathematical learning. This is interesting given the long historical relationship between the cognitive sciences and neurosciences in the early years' context. In the following section we examine these findings alongside the Australian primary and secondary mathematics curriculum.

Like the Early Years Learning Framework for Australia (V2.0) the Australian Curriculum Mathematics (V9.0) is aligned with achieving the two goals of the Mparntwe Education Declaration (2019). The Australian Curriculum Mathematics (V9.0) is focused on the first 11 years of formal schooling and aims to ensure that students:

- become confident, proficient and effective users and communicators of mathematics, who can investigate, represent and interpret situations in their personal and work lives, think critically, and make choices as active, engaged, numerate citizens
- develop proficiency with mathematical concepts, skills, procedures and processes, and use them to demonstrate mastery in mathematics as they pose and solve problems, and reason with number, algebra, measurement, space, statistics and probability

– make connections between areas of mathematics and apply mathematics to model situations in various fields and disciplines
– foster a positive disposition towards mathematics, recognising it as an accessible and useful discipline to study
– acquire specialist mathematical knowledge and skills that underpin numeracy development and lead to further study in mathematics and other disciplines.
(ACARA, 2024)

It is not surprising, given the strong presence of the cognitive and neurosciences in the Early Years, that in the Foundation Year of the Australian Curriculum Mathematics (V9.0) 65% of the curriculum is focused on number, numerosity, quantity and quantifying. This aligns with the Early Years Learning Framework for Australia (V2.0) and appears to encompass many of the insights evident across the cognitive and neuroscience research base reviewed (Anobile, 2021; Hyde, 2021; Guerrero & Park, 2023; Visibelli et al., 2024). Apart from measurement, the remainder of the Foundation Year of the curriculum aligns with the Early Years Learning Framework for Australia (V2.0) in that it involves learning through bodily movement. Given that number, numerosity, quantity and quantifying is a significant component of measurement it would be reasonable to suggest that it too has been informed by the strong presence of the cognitive and neurosciences in the Early Years.

The emphasis on number, numerosity, quantity and quantifying continue throughout the Australian Curriculum Mathematics (V9.0) and is developmentally progressive in nature. This is in direct alignment with the school-based literature reviewed which was still firmly situated in understanding arithmetic thinking and number (Guerrero & Park, 2023; Fang & Zhou, 2022). Whilst the school-based literature reviewed extended this understanding by providing insight into new concepts such as visual working memory, cognitive load and perception (Fang & Zhou, 2022; Chen et al., 2023), these new insights were not evident within the curricula documentation. Given that the research reviewed was primarily situated in examining numerosity, quantification and arithmetic thinking it is impossible to draw any conclusive conclusions on the influence of the cognitive and neurosciences on the other areas of the Australian Curriculum Mathematics (V9.0).

5 Discussion

The integrative review of literature presented in this chapter was limited by the three-year focus. Despite this limitation, it did uncover some interesting findings, particularly in relation to how the research is translated into curriculum documentation. A key finding that has emerged through the integrative review is the complexity of the cognitive and neurosciences as a changing and emerging field of research. Despite being a prominent feature in the early years' curriculum over the past eighty-plus years, new developments (possibly fostered by new and emerging technologies) are still being explored. On the surface, this complexity and the rapidness of new findings might be thought to have hindered research-to-practice and contributed to a time lag in curriculum documentation. However, in relation to the early years context this does not appear to be the case.

The Early Years Learning Framework for Australia (V2.0) reflects an underpinning foundation of numerical cognition, working memory and its role in numerical learning, number sense, and arithmetic ability which would indicate that recent findings in the cognitive and neurosciences have filtered through to the new curriculum document. Whilst there still appears to be a gap in relation to the role of physicality and play-based learning (prominent vehicles for mathematics learning in the years context) in the cognitive and neuroscience research base this may also be due to the focus on understanding learning (rather than teaching) within the field. Hawes and colleagues provide a useful example of how this gap might be addressed (Hawes, et al., 2021).

The formal school mathematics curriculum documentation also appears to reflect the current field of research although there were some limitations that were also uncovered. Like the early years' curriculum documentation, there appears to be limited research that explicitly targets other areas of the curriculum. This might centre around a well-known proposal "that numerosity perception is the cognitive underpinning of mathematics ability" (Sun, et al. 2021, p. 1); and whilst there is no doubt that numerosity perception plays a crucial role in mathematical understanding a widened focus into other areas of the mathematics curriculum might strengthen the links between theory and practice.

In the review presented in this chapter, curriculum lag appears to be centred around the narrow focus of numerosity and numerical thinking that the cognitive and neurosciences have adopted in examining mathematics learning rather than a gap of translating theory to practice. Albeit whilst it appears that current research findings and direction are reflected in some ways in the two curriculum documents, it has been difficult to establish how the explicit findings of the research reviewed are directly infiltrating the wider mathematics curriculum.

A promising and novel perspective in relation to how to overcome any curriculum lag in the mathematics curriculum across early years and formal schooling contexts has been highlighted by Hawes et al., (2021). This perspective recognises that the teacher has a very significant role in enabling learning to happen. For "to actively engage children, educators identify children's strengths, choose appropriate teaching strategies and content, design the learning environment, and collaborate with children to co-construct learning" (AGDE, 2022, p. 8). Educators' professional judgments are also central to their active role in facilitating children's learning. In making professional judgements, they intentionally weave together their:

- professional knowledge and skills
- contextual knowledge of each child, their families and communities
- understanding that relationships with children and families are critical to creating safe and trusting spaces
- awareness of how their beliefs and values impact children's learning and wellbeing
- knowledge and understanding of Aboriginal and Torres Strait Islander perspectives
- personal styles and past professional experiences
- use of all components in the planning cycle.

Alongside their professional knowledge educators draw on their creativity, intuition and imagination, including engaging in critical reflection to evaluate and adjust their practice to suit the learners, the time, place and context of learning. (AGDE, 2022, p. 12). If curriculum lag is to be truly addressed and cognitive and neuroscience research is to have an authentic impact on mathematics learning, like Hawes and colleagues have recognised,

> Indeed, educators' knowledge of children's numerical thinking has been shown to be a powerful driver of instructional change, associated with improvements in children's numerical reasoning, and self-reported understanding and confidence in problem-solving abilities. (Hawes et al., 2022, p. 3)

Centralising and operationalising teachers to provision for and address curriculum lag provides a novel and new perspective for translating theory into classrooms and into curriculum documentation. This might involve reconceptualising current ways of curriculum development and investment and incentive for researchers to share their findings with teachers to enhance professional learning. Investing in this process would ensure that teachers maintain currency and that children are learning through current research perspectives. In relation to curriculum development, it would involve a bottom-up approach where researchers and teachers inform curriculum rather than curriculum be developed externally which is the common practice. Investment in this process might also open avenues that widen the research lens and focus in more holistic ways on all areas of mathematics learning.

6 In Summary

The cognitive and neurosciences offer exciting avenues for deepening understandings about mathematics learning and how it might be supported and nurtured in the educational context. Whilst the integrative review presented in this chapter has provided some interesting insights, it remains unclear as to whether these insights are being translated into practice. Addressing time lag as an issue for curriculum development is a significant challenge facing governments in numerous countries from around the world, particularly in relation to the current explosion of new technologies and the advancements in knowledge that this explosion has afforded. Whilst we have not been able to determine conclusively whether time lag is an issue in the Australian Curriculum Mathematics, we offer insight into a new perspective that can be drawn on by policymakers to ensure that new and current research developments filter directly through to teachers, children and curriculum in more timely and impactful ways.

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