Chapter 3
A Philosophical Gaze on Australasian Mathematics Education Research

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Abstract This chapter examines the philosophical underpinnings of Australasian mathematics education research between 2012 and 2015. It takes a hermeneutic approach, seeking to uncover often hidden assumptions about ontology, epistemology, aesthetics, ethics and logic. The first part of the chapter explains the approach taken and outlines the set of papers considered. The chapter then examines the set of keywords used in Australasian mathematics education research papers published in major international journals, seeking to identify broad themes or omissions. It then takes a more detailed look at a purposive selection of 26 papers, chosen to reflect the themes in this Review. Finally it examines papers that explicitly discuss epistemology to identify researchers' underlying assumptions about the nature of knowledge and its acquisition. The chapter points to some important tensions within the research and suggests that such tensions can be used as a creative force to enable mathematics education researchers to better identify and question the philosophical assumptions that underpin their research.

Keywords Aesthetics · Education research · Epistemology · Ethics · Hermeneutics · Logic · Mathematics · Ontology · Philosophy

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1 Introduction

> …the present community of mathematics educators lives in an academic environment with colleagues driven by a variety of frameworks, including various socio theoretical perspectives, and postmodern views of the world. Given that the resulting environment creates pressures and tensions for scholars subject to a cross fire of paradigms, what are the implications for individuals for whom both MATHEMATICS and EDUCATION are spelled in capitals? (Galbraith, 2014, p. 40)

Peter Galbraith's keynote at the 2014 Mathematics Education Research Group of Australasia (MERGA) conference, from which the above quotation is taken, highlighted the dilemmas faced by mathematics education researchers bombarded with a range of perspectives, ranging from what might be termed an extreme "post" view of the world, where everything is open to question, to an extreme "reductionist" view of the world, where absolute statements are made and research is removed from context. Of course, we can learn much from different perspectives, no matter how extreme, but how do we choose between competing views of the world? Have we, as mathematics education researchers, become hostage to a particular view of the world, and if so, how do we become more aware of the implications? Or have we become blind to the underlying assumptions about the world that drive our work?

In this chapter we attempt to address these deep questions about the assumptions that underpin mathematics education research. For we maintain, like the philosopher Alasdair MacIntyre (2011, p. 72), that "every action is the bearer and expression of more or less theory-laden beliefs and concepts; every piece of theorising and every expression of belief is a political and moral action." We are aware that trying to identify the theories and beliefs underpinning the research carried out in mathematics education in Australasia from 2012 to 2015 is a monumental task, and even were we to read and comment on every piece of literature we would undoubtedly get it wrong. Nevertheless we hope that in adopting a philosophical gaze on the mathematics education research literature we can at least heighten the awareness of the mathematics education community to those theories and beliefs, and hence hint at what might be "the implications for individuals for whom both MATHEMATICS and EDUCATION are spelled in capitals."

2 What Do We Mean by Philosophical?

In this section, we position the chapter by discussing five major dimensions of philosophical endeavour and raising questions about how these relate to mathematics education. These are:

- Ontology (metaphysics): the nature of being, becoming, existence, or reality. We ask what aspects of mathematics education are "taken as given" in the research. What do different research paradigms or theoretical frameworks used in the research assume about the nature of reality?

- Epistemology: the study of knowledge and justified belief and how we come by it. We ask are different views of knowledge evident in the mathematics education research. If so, how do these epistemological positions impact upon mathematics in the classroom and on the methods and outcomes of the research?
- Aesthetics: judgement about matters of value. We ask what values appear to underpin the research and how do they impact upon the positions adopted by teachers and researchers with respect to curriculum or pedagogy.
- Ethics: systematising, defending and recommending concepts of right and wrong conduct. We ask how does the research embed or contribute to a heightened sense of ethical awareness.
- Logic: the use and study of valid reasoning and argumentation. We ask what different approaches to reasoning are used in the research. How do these different approaches position the research with respect to its capacity to be generalised or contextualised?

We first distinguish between our use of the term philosophy and terms such as theory, paradigm, methodology and model. The boundaries between these concepts are obviously blurred, however in this chapter we focus our attention on the five philosophical dimensions outlined above. Hence, while theoretical perspectives such as sociocultural theories of learning used, for example, in research by Goos (2014), have epistemological and ontological underpinnings, we do not discuss these theories or their use per se, except as they relate to the dimensions outlined above. Nor do we specifically discuss poststructuralist paradigms used, for example, by Klein (2012) or Walshaw (2013), models of mathematics education such as mathematisation used, for example, by Stillman and Brown (2014), or methodological approaches such as design research used, for example, by Cortina, Visnovska, and Zúñiga (2013), again, except as they relate to the dimensions discussed above. Of course, each of these, and every other, theory, paradigm, model or methodology has philosophical underpinnings that make assumptions about the nature of reality, the nature of knowledge, what is valued and how choices are justified. Hence, rather than discussing this literature explicitly, our survey of the research adopts a hermeneutic approach in trying to uncover underlying philosophical positions adopted, although most commonly not explicitly identified, by researchers across a broad spectrum of mathematics education research.

We are also conscious that philosophy has a strong political dimension, as any position on the nature of reality or knowledge, or set of values, necessarily has political implications. Four studies in particular addressed political aspects of mathematics education (see Chap. 4, this volume). Thornton (2013) discussed metaphors of mathematics education, arguing that dominant metaphors of education, including the school as factory and school as clinic, have been replaced in political rhetoric by a metaphor of education as a race, evidenced by the drive for competitiveness in tables of educational rankings such as the Programme for International Student Assessment (PISA) and the Trends in International

Mathematics and Science Study (TIMSS). He proposed an alternative metaphor, termed *Slow Maths*, in which culture and context are at the forefront of educational thinking. Thornton (2014) also discussed how the drive for success in system-wide tests is evident in a state education system policy document, arguing that the dominant rhetoric is located in Heidegger's concept of the technological enframing. The technology of assessment was also discussed by Seddon et al. (2013) in relation to the impact of the Excellence in research for Australia (ERA) on educational research in Australia. They noted that knowledge-based regulatory tools such as the ERA produced "unintended consequences…that present contradictory imperatives and expectations that create moral and political dilemmas" (p. 435). Lange and Meaney (2014) surveyed press releases and news articles regarding national testing, and argued that in such articles students are "positioned as commodities with mathematics achievement being the value that can be added to them" (p. 377). They concluded that this view of students has both social justice and pedagogic implications. They argued that it disadvantages schools, predominantly those populated by students of low socioeconomic status that are perceived to perform poorly, and narrows teaching and testing approaches to those that most obviously fit the test. Such studies offer a word of caution to those who place undue emphasis on the outcomes of system-wide tests, or to those who unquestioningly adopt the rhetoric of learnification (Biesta, 2010, as discussed in Atweh, Miller, & Thornton, 2012) assumed by such testing regimes. While a more thorough discussion of political dimensions within mathematics education research would be both informative and timely, we restrict ourselves here to the observation that the critique within each of these papers suggests that dominant paradigms in systemic approaches to mathematics education are underpinned by a somewhat reductionist and positivist ontology in which results in accompanying testing regimes are taken as true indicators of the outcomes of education.

Positioning philosophy as a provocateur for thinking about mathematics and education thus raises challenging and unsettled questions for which there are no easy or exact answers. It contains both descriptive and normative elements in that it discusses how things are and how things ought to be. It provides a way of addressing things that are important to us, and of questioning the values and beliefs that we hold. This was very much our approach in writing this chapter. We make no claims regarding the veracity of our findings in any absolute sense. Our use of a framework such as that described above necessarily privileges a particular reading of the research literature. Rather, we used our reading and analysis as a vehicle for critical reflection on how we view the world and what we value. We invite the reader, not only in this chapter but also throughout the Review, to do likewise and engage in critical reflection about the ontological, epistemological, aesthetic, ethical and logical questions highlighted above.

3 What Do We Mean by Gaze?

In this section we discuss our approach to the literature, and the methodology used in analysing it. An initial literature search using keywords such as "mathematics AND education AND philosophy" or "mathematics AND education AND ethics" revealed no results from the Australasian mathematics education research literature. However this does not mean that the philosophical questions raised above are unimportant. Rather, we suggest that they are so much a part of researchers' identities that they are often hidden to their own gaze. We therefore adopt a hermeneutic perspective to try to see below the surface and identify the philosophical positionings that are embedded in the research.

The hermeneutic approach maintains that a text, context and reader are inextricably related. A text cannot be fully appreciated without understanding the context in which it is set, and the reader is thus obliged to try to understand the author's context, and to make sense of the text in her own context (Lerman, Xu, & Tsatsaroni, 2002; Lester & Wiliam, 2002). A key part of the context in which a text is set is the author's philosophical, that is their ontological, epistemological, ethical, aesthetic and logical, position. Hence we developed a template with which we examined a selection of Australasian mathematics education research papers. Appendix 1 shows an example of how the template was used to examine a paper by Fielding-Wells, Dole, and Makar (2014). Each of us independently read and examined this paper and made comments relating to the assumptions that appeared to underpin the research. We compared responses to ensure a degree of consistency in our interpretation and approach, and collated our responses into one document. Even in this reading of one paper it was apparent that certain assumptions are made in the research about the nature of knowledge and how it is developed, the purpose of mathematics education and what is valued, and the purpose of mathematics education research and its relation to teachers. A close reading, such as this, of every Australasian mathematics education research paper published between 2012 and 2015 would, of course, be impractical. Hence to ensure that we examined a selection of papers dealing with a variety of topics and likely to adopt a range of philosophical positions we collated the keywords from every Australasian-authored paper in the major mathematics education journals: *Mathematics Education Research Journal*, *Mathematics Teacher Education and Development*, *Educational Studies in Mathematics*, *Journal for Research in Mathematics Education*, *Journal of Mathematical Behavior*, *Mathematical Teaching and Learning*, and *ZDM—The International Journal on Mathematics Education*. We then searched for keywords likely to be closely linked to each of the subsequent 13 chapters in this Review, and selected, either at random or based on recommendations from the chapter authors, two papers that we felt were likely to be prominent in each of these 13 chapters, giving us a purposive sample of 26 research papers, for each of which one of us completed a template similar to that shown in Appendix 1. The findings from this hermeneutic examination are presented in Sect. 5.

We further used our keyword analysis as a data set in its own right. By examining the frequency of each of the keywords and looking for trends, we hoped that we would uncover philosophical dimensions of the mathematics education research that are particularly prominent or absent. We present these data in Sect. 4.

Finally we searched our database of some 130 papers in mathematics education research journals for the term *epistemology*, or variants thereof. While we recognise that ontology logically underpins epistemology, an author's epistemological stance suggests much about their ontological beliefs. Hence, in the literature epistemology is likely to be both prominent and revealing. We found more than 20 occurrences, and examined each of these for use and meaning. We present the results of this examination in Sect. 6.

4 What Do the Paper Keywords Suggest?

In an attempt to make sense of what the keywords suggested we classified them according to their focus. Our initial categorisation included 23 concepts such as research methods, levels of schooling, discourse or knowledge and cognition. We then further categorised the keywords into the six main headings shown in Table 3.1. We are aware that such broad categories mask the finer details of the initial 23 categories, but we suggest that they do say much about the focus of the studies carried out in Australasian mathematics education research. Not surprisingly mathematics content, classroom practices and how students understand or relate to mathematics teaching were the major foci of Australasian mathematics education research. Research methods, theories and the contexts in which research is conducted were also highlighted in a significant number of papers, while a large number focused on teacher knowledge or teacher education. Only 13 keywords related to goals of education or ethical considerations, which we suggest reflects the relative lack of explicit attention paid to the philosophical underpinnings of mathematics education research. Given the attraction of a specific journal to like-minded authors and readers, it is likely that authors did not consider the necessity to make such positions explicit. While we cannot claim that keywords alone indicate authors' philosophical positionings, they are suggestive of what authors consider to be of primary importance in a paper. We therefore suggest in passing that researchers give consideration to using more explicit terms in their keywords.

Table 3.1 Categorisation of keywords

Mathematics (content, application, curriculum, processes)	142	29 %
Classroom (pedagogy, assessment, tools, discourse)	128	26 %
Students (levels, geolocation, cognition, beliefs, affect)	105	21 %
Research (methods, theoretical underpinnings, contexts)	57	12 %
Teachers (education, development, knowledge)	50	10 %
Goals and ethics	13	3 %

We turn now to a closer examination of the keywords in a selection of papers. All research rests on ontological assumptions about the form and nature of the reality being studied. Few keywords made explicit the authors' assumptions relating to the issue of what reality is like, however many implied different ontological assumptions. For example, Meaney and Evans (2013) who used the keyword *ethnomathematics* argued that the Western worldview is at odds with the worldview of Indigenous communities. Counting as accumulation, it is proposed, is more appropriately replaced, in some Indigenous communities, with counting for sharing. Underpinning this argument is a position that asserts that realities are local, specific, and constructed, and hence, everyday understandings, as well as symbols such as language, are prominent in such research. In contrast, Lim and Chapman (2015) used the keyword *scale development* and described the development and validation of an academic motivation scale in Singapore. Such research measures student attributes in an objective system where different types of motivation have different worth.

Many papers included epistemologically-related keywords such as *indigenous knowledge*, *mathematics teacher knowledge*, *pedagogical content knowledge*, and *conceptual knowledge*. Others gave explicit attention to the philosophies of knowledge production associated with, for example, *Vygotsky*, *enactivism* or *inquiry-based learning*. Keywords that identify specific types of knowledge or draw on seminal work of key figures make epistemological assumptions about what constitutes knowledge of the reality being studied. Research reported in these papers addressed epistemological questions concerning who has access to valued knowledge, how such knowledge is acquired and which knowledges are valued over others.

A few papers used keywords with an obvious aesthetic dimension such as *creative mathematical problem solving*, *persistence*, *authentic investigation* and *values*. Such keywords highlight that mathematics should be more than a body of knowledge: they are concerned with highlighting mathematics as something that is meaningful and relevant to students, allowing them opportunities to solve problems in a variety of ways and to develop productive habits of mind.

Keywords such as *equity* (see Chap. 7, this volume) and *care theory* highlighted ethical dimensions, exposing structures, arrangements, beliefs and practices that are inequitable and that impose constraints to students' or teachers' constructions of knowledge. These papers highlighted the goal of emancipation: participants will be able to change their circumstances and will be able to create a more just and more democratic place for themselves within the world of mathematics education.

A large number of keywords focused on particular aspects of mathematics and reasoning. These included such terms as *functional thinking*, *spatial reasoning*, *proportional reasoning* and *informal statistical inference*. Such keywords hint at the logic employed in mathematical reasoning, in some cases suggesting that mathematical reasoning is to be valued above everyday logic and in others suggesting that informal knowledge is a key aspect of children's mathematical development. Implicit within papers emphasising informal reasoning is the understanding that people are constantly making sense of their worlds and that truth is socially and experientially based, embedded in ongoing social interactions.

5 What Does a Hermeneutic Reading of a Sample of Papers Suggest?

Using the methodology and conceptual framework described above, we examined 26 research papers from the Australasian mathematics education research literature, comprising two papers likely to be the subject of review from each of the following 13 chapters of this Review.[1] At this more sophisticated level of analysis, we looked beyond keywords. We searched the publications for evidence of how authors' ways of "reading" the world played out in their research. Our hermeneutic approach sought to uncover some unstated assumptions that lay beneath the topic chosen, the way the research was conducted, or the conclusions drawn. We now present our analysis of how each of the five philosophical dimensions discussed above may have been embedded in the mathematics education research literature.

Our analysis suggested not unexpectedly, that authors held a range of ontological perspectives, however these perspectives were on the whole inferred from the epistemological dimensions of the paper rather than explicitly stated. Most papers (e.g., Barton, Oates, Paterson, & Thomas, 2015) appeared to position mathematical truth as a socially constructed reality located in collective and agreed meaning making, with mathematical concepts thus seen as fluid and evolving, rather than fixed and stable. Further to this approach, some papers viewed culture as the determiner of mathematical purpose, with mathematical thinking and concepts differing culturally. From this perspective, mathematics is a subjective experience, with meaning residing in the individual.

Conversely, some papers (e.g., Stillman & Brown, 2014) emphasised mathematics as accessed through and existing in the physical systems of the world. As a consequence, models of the world can be constructed and represented mathematically, which in turn enables real problems to be solved. The mathematical modelling process therefore makes certain assumptions about the nature of reality and the capacity of mathematics to encode that reality. Several papers (e.g., Zhang & Stephens, 2013) implicitly assumed mathematics to be hierarchical and sequential, with an accompanying deconstruction of whole to part, a perspective on mathematics that we suggest is strongly located in and defined by formal curriculum.

Unsurprisingly, given the ontological perspectives we identified above, the template analysis indicated a strong epistemological focus on the acquisition and development of conceptual knowledge. In mathematics *education* research, acquisition of conceptual knowledge targets how we come to know and therefore

[1] A complete list of these 26 papers is given in Appendix 2.

teach mathematics. The prevalence of this theme accords with Schoenfeld's (1992) observation that ontological perspectives about mathematics drive goals, and hence form the basis for mathematics instruction. Epistemology, ontology and pedagogy are therefore inextricably intertwined in this regard, and we now discuss the dominant *pedagogical* themes found in our analysis.

Across the papers, mathematical learning was strongly positioned as dynamic (e.g., Cavanagh & Garvey, 2012), in that we come to know mathematics through active co-construction and social participation, by discussing and engaging in argumentation and questioning, and by engaging in communities of practice. As a result, mathematical knowledge can be intuitive, contested, and subjective. Many papers (e.g., Fielding-Wells, Dole, & Makar, 2014) suggest that we learn mathematics by working in disciplinary practices; through generalising, conjecturing, inquiring and proving, and by working with mathematical procedures (e.g., Roche & Clarke, 2013). We gain mathematical knowledge by interpreting, reflecting, playing, making errors and risk-taking (e.g., Gervasoni & Perry, 2015). We access the physical reality of mathematics through solving problems we encounter in the world, a process that enables connected, systems (relational) knowledge to develop and we can represent and model the real world problems we encounter and solve (e.g., Ho & Lowrie, 2014). Because real world problems are contextual, some research (e.g., Owens, 2015) highlighted that culturally dissimilar mathematical knowledge is accessed in different ways, and mathematical knowledge is therefore dependent on cultural identity.

Aesthetics was the least visible dimension in our template analysis. Our definition of aesthetics was broad, encompassing matters of value and the relationship between values and curriculum and pedagogy. As a result, we found underpinning themes about the worth of mathematics (e.g., Thomas & Klymchuk, 2012), the valuing of student-teacher and peer relationships, and well-being (e.g., Averill, 2012) which were not clearly attributable to a paper's ontological or epistemological dimensions. However, the moving, beautiful and sublime dimensions of aesthetics that many of us appreciate in mathematics were notably absent in the papers we reviewed. We wonder if it is time to re-evaluate and re-invigorate discussion of aesthetic dimensions of mathematics, and to consider and investigate how such dimensions might positively influence mathematics teaching and students' learning.

Although the ethical dimension was less visible than the ontological or epistemological dimensions, many papers explicitly discussed ethical responsibilities to different groups of learners (see Chap. 7, this volume for a more detailed discussion of diversity). Here the calls were for greater acknowledgement of, and accommodation for, diversity in culture and student needs, such as those of Indigenous, special needs and gifted and talented students (e.g., Bicknell & Riley, 2012; Clarke & Faragher, 2014), and for teachers to adopt a culturally responsive approach to meet and embrace these differing needs (e.g., Meaney & Evans, 2013). In some cases (e.g., Anthony, Hunter, & Hunter, 2015) these ethical considerations extended to asking practising or pre-service teachers to consider the importance of reflective practice when examining the moral and ethical dilemmas found in their professional experiences with diverse learners. We note however that outside the 26 papers surveyed here, there has been growing discussion of the importance of ethics in Australasian mathematics education (see also Chap. 6, this volume). Atweh (2013) highlighted the apparent exile of ethical considerations in mathematics education research, arguing that much research focuses on *good* mathematics, rather than on mathematics *for the good*, making an implicit assumption that if the general population becomes better at mathematics, society will necessarily become more just. He maintained (Atweh, 2012) that ethics should precede ontology and epistemology in considering what counts in mathematics education, "making the assertion that ethics is not an add-on to the concerns in mathematics education. It lies at the very foundation of every decision in the field" (p. 340).

Ethical dimensions specific to the social value and purpose of mathematics education and learning mathematics (e.g., Lange & Meany, 2014) were also visible. While some research (e.g., Pierce & Stacey, 2013; Wilkie, 2014) implicitly assumed that there was a right way of "doing" mathematics or applying mathematical knowledge, other research (e.g., Muir, 2014) positioned knowledge, resources or procedures as something that could be freely chosen and applied openly and flexibly when learning and problem solving. We suggest that the extent to which students are free to choose and apply particular methods for solving problems is an ethical dimension of mathematics learning. Regardless of the outcome of such decisions however, we suggest that fostering intellectual dispositions in learning mathematics should characterise all mathematical learning and be made a more explicit focus of mathematics education research. Described by Sockett (2012) as intellectual virtues, these include qualities such as engaging accuracy, truthfulness, impartiality and open-mindedness.

Our analysis of the dimension of logic suggested that most mathematics education research papers use inductive approaches to research, data analysis and questions of generalisation. We identified consistency in the logical structure in the way research was presented, in connections between methodology and method, and in the congruence between data and discussion. We also observed that researchers remained faithful to the chosen methodology; for example, a hermeneutic study (e.g., Calder, 2012) applied the interpretive logic inherent in the theory. The importance of logical reasoning in mathematical *learning* was also evident in many papers (e.g., Fielding-Wells et al., 2014; Logan, 2015), where the role of explanation and justification and of normative validity was discussed. Few if any of the papers we examined however could make claims to using forms of logic that would be expected when engaging the discipline of mathematics itself. We suggest that there may be a place for reinvigorating logical, evidenced reasoning and rigorously argued reporting in mathematics education research.

6 What Do Specific References to Epistemology and Ontology in the Mathematics Education Research Literature Suggest?

As one might anticipate, in the mathematics education research literature the term *epistemology* was by far the most commonly occurring of the five areas of philosophical inquiry framing our chapter. Of the 139 papers that we identified in major educational research journals that were at least co-authored by a researcher associated with an Australasian university, 24 included the term epistemology or a variant thereof somewhere in the paper. In this section we attempt to draw together the epistemological perspectives in these papers, and to highlight the implications of particular epistemological positionings for mathematics education.

However, as highlighted by Galbraith (2014) in the quotation at the beginning of this chapter, there is by no means a common view on either what we mean by epistemology or on how knowledge building is best promoted in the mathematics classroom. This diversity of epistemological perspectives was the subject of a paper by Adam and Chigeza (2014) who discussed binary oppositions between different pedagogical approaches and perspectives and showed how these are related to epistemically relevant binaries. They maintained that "the coordination of these different and seemingly contradictory assumptions presents a 'wicked problem' for mathematics educators" (p. 109) that ultimately impacts significantly on students' attitudes towards mathematics.

Reflecting on a long involvement in mathematics teacher education, Klein (2012) similarly highlighted the "inadequacies of contemporary theoretical and philosophical orthodoxies to fully address pedagogic change" (p. 25) and used a bifocal lens of psychological and post-structuralist constructs to highlight how power relations are inextricably connected to the construction of knowledge among pre-service teachers. In writing her paper, Klein aimed to "encourage fellow educators and researchers in mathematics education to continue to search out new perspectives in relation to theories, philosophies and ontologies that inform changes in instructional practice" (p. 39). From a similar post-structuralist perspective Walshaw (2012) argued that social justice is an epistemological issue. She claimed that a post-structuralist perspective and vocabulary provides ground for taking ethical practical action in a new epistemological context. For Walshaw, this is more than a mere construction; post-structuralist perspectives "open up the possibility of intervention through a commitment to social and educational change" (p. 117). Similarly Valero and Meaney (2014) argued that "scholarly work has the ethical commitment of pushing the limits of existing research discourses in the forming of the epistemological frameworks that format conceptions of practice" (p. 984).

Such commitments have been explored by a number of the authors who specifically highlighted epistemological issues. McMurchy-Pilkington, Trinick, and Meaney (2013), for example, discussed curriculum reform in New Zealand, describing how contestation over language and epistemology enabled a mathematics register for the Maori language to be modernised, in the process revitalising language and ideally leading to a more inclusive and culturally responsive curriculum. Meaney and Evans (2013) similarly discussed the values and purposes of school mathematics for Australian Indigenous students, arguing that we must take seriously both Indigenous epistemologies evidenced in traditional mathematical ideas and ways of knowing, and the imperative to learn school mathematics. They argued that achievement in system-wide assessments should not be considered the pinnacle of success for Indigenous students. Writing in a special issue of the journal *Learning Communities* on ethnographic stories of disconcertment, MacMahon (2013) described the both-ways approach to mathematics at Yirrkala in northern Australia, highlighting the disconnect between the assumption of epistemic equality that lies at the heart of the individualistic epistemologies of western mathematics and the person-specific meanings that underpin Indigenous epistemologies in that context. Lipka, Wong, and Andrew-Ihrke (2013) also discussed how Indigenous epistemologies, in their case those of the Yup'ik Eskimos, are brought into dialogue with academic mathematics, while Hooley and Levinson (2014) compared the educational experiences of UK Roma gypsies and Indigenous Australians, asking whether it is possible for formal educational systems to be inclusive and democratic by connecting with the epistemological views of marginalised groups and acknowledging their history, culture and identity. Averill (2012) suggested that it is, and explained how through explicit attention to Maori ways of knowing and being, it is possible to develop a culture of care in the mathematics classroom that is both inclusive and responsive. While it is not our purpose to pre-empt the discussion of mathematics for Indigenous students later in this Review (see Chap. 8), we suggest that the issues highlighted by these authors are deeply epistemological in nature, and that efforts to raise the achievement of disadvantaged or marginalised groups will not be effective unless such epistemological questions are addressed.

Several of the studies discussed above are specific in identifying the epistemic impact of different worldviews held by Indigenous and non-Indigenous people. An interesting variation of this is a study by Chan and Wong (2014), who examined the connection between ontology, epistemology and religious beliefs in mathematics. They described three representative teachers of mathematics: one Buddhist, one Christian but strongly influenced by a Confucian worldview, and the third an evangelical Christian. They suggested that Catholic and Protestant religious views tend to result in beliefs about mathematics as calculable and precise, while worldviews of Chinese origin orient the believer to see mathematics as primarily involving thinking. The Buddhist teacher in their study had what they considered to be stronger constructivist views about mathematics, and saw greater unity between mathematics and their view of the world. They described the Buddhist teacher as having a "connective epistemological worldview" (p. 268). Calder (2012) critiqued a view of mathematics similar to that found by Chan and Wong in the teacher of Christian persuasion as fixed and precise, arguing that mathematical concepts evolve rather than present themselves as fixed realities. In a study of the use of digital media such as spreadsheets and *Scratch* in pre-service teacher education, he adopted a hermeneutic perspective, stating that "understanding is a process rather than a position and a 'concept' is a shared consensus rather than an irrevocable truth" (p. 272). Mathematics itself, then, is "an evolving set of perceptions, with each iteration of interaction, interpretation and explanation either extending its edges or refining it core identities" (p. 282), and learning is an ongoing condition of becoming. Nason, Chalmers, and Yeh (2012) also examined the use of ICT tools, in particular *Knowledge Forum*, in pre-service teacher education. The tool is explicitly epistemic, providing a vehicle through which students can collaboratively build knowledge through the processes of wondering, conjecturing and hypothesising.

Bautista and Roth (2012) discussed underlying ontological assumptions about mathematics, which are exemplified in children classifying three-dimensional shapes through bodily movements and physical manipulation. Their study was framed within a theory of what they term "mathematics in the flesh" in which "mathematics does not constitute a corpus of transcendental and decontextualized abstract ideas, but a phenomenon only existing with/in our lived/living body" (p. 91). The mind/body duality highlighted in this study was further discussed by Roth (2012) in a theoretical exploration of the application of cultural historical activity theory (CHAT) to mathematics education research. He argued that traditional applications of Vygotskyian social constructivist theories maintain an external/internal duality and tend to emphasise static perspectives of activity rather than highlighting its dynamic nature. An interesting contrast to Roth's external/internal duality was provided by McDonough and Sullivan (2014) who looked at the beliefs and knowledge of young children through creative interviewing procedures. While Roth maintained that knowledge and beliefs represent external and internal manifestations of an individual's mathematical persona in a social context, McDonough and Sullivan explicitly started from the premise that beliefs are an internal individual construct, while knowledge is an external social construct. Afamasaga-Fuata'i and Sooaemalelagi (2014) also highlighted different aspects of mathematical action using a modification of Gowin's epistemological vee diagram. The thinking and doing sides of the epistemological vee enabled Samoan pre-service teachers to record and reflect on their attitudes, investigations and metacognitive tools.

A number of authors who highlighted epistemological aspects of their research discussed sociocultural approaches of learning. Goos (2014) used Valsiner's zone theory to examine how sociocultural perspectives can inform research that seeks to have an impact on classroom practice in the context of professional learning on technology integration. She described how a teacher's Zone of Proximal Development, in interaction with the Zones of Free Movement and Promoted Action, has deep epistemological underpinnings; it becomes "a set of possibilities for the development of new knowledge, beliefs, goals and practices created by the teacher's interaction with the environment, the people in it, and the resources it offers" (p. 523). Anthony, Hunter, and Thompson (2014) used cultural historical activity theory (CHAT) to trace one teacher's learning journey, highlighting the dialectic tensions at the epistemological level of the classroom. The teacher's increasingly rich understanding of these tensions, examined through Activity Theory, empowered him to think in new ways and to transform his teaching through what the researchers termed "expansive learning". Roth and Gardner

(2012) used CHAT to examine how electrical apprentices in Canada cross boundaries between formal schooling and the workplace, suggesting that the gap between the formal and work discourses appears to arise from an epistemology that "tends to endorse the valuation of abstract knowledge over actual practice and, as a result, to separate learning from working, and, more significantly, learners from workers" (p. 187).

Several other authors pointed to the epistemological gap between abstract mathematical knowledge and the contextual knowledge required in the workplace. Coben and Weeks (2014) facilitated the boundary crossing highlighted by Roth and Gardener (2012) through the provision of dynamic online virtual environments that closely match the workplace environment of nurses who are required to accurately administer medication dosages. Ramful and Narod (2014) discussed the epistemological gaps between students' reasoning in mathematics and chemistry, using Vergnaud's theory of conceptual fields to examine students' use of proportional reasoning. Building on the premise that "mathematical concepts exist in relation to each other and draw their meaning from a variety of situations" (p. 30) they described the complexities involved in the simultaneous use of chemistry knowledge and mathematical knowledge and argued for collegial collaboration between chemistry and mathematics education researchers.

Epistemological gaps and obstacles were also the subject of several mathematics-specific research papers. Hong and Thomas (2014) identified epistemological gaps and changes required in students' understanding of differentiation and integration in the transition from school to university. They described how digital materials designed to provide an improved cognitive base through a flexible, proceptual understanding of key ideas of calculus help to address these gaps and develop versatile thinking. Cortina, Visnovska, and Zúñiga (2013) used Brousseau's classification of ontogenetic obstacles, epistemological obstacles and didactical obstacles, arguing that didactical obstacles should be avoided, but that ontogenetic and epistemological ones should be faced. They outlined three images of equipartitioning of fractions that present didactical obstacles, arguing for a more widespread re-examination of assumptions about teaching and learning. The gaps between children's perceptions of reality and the world of mathematics were highlighted by Ben-Zvi, Aridor, Makar, and Bakker (2012) in their investigation of grade 5 students' development of informal statistical reasoning. They used Polanyi's theory that when faced with a problem people first develop a hypothesis drawn from personal beliefs and experiences, and that when faced with contradictory evidence, such evidence is often ignored or unseen. They claimed that the act of reconciling evidence with beliefs is an epistemological act, and described how the epistemological gap in informal statistical reasoning can be bridged through the use of growing sample sizes. Makar (2014) also investigated grade 3 students' informal inferential reasoning about the typical heights for grade 3 children, suggesting that an inquiry process built on epistemic argumentation can help to bridge the real world/mathematical world gap. Fielding-Wells et al. (2014) reported on the impact of epistemic argumentation to promote proportional reasoning. The grade 4 children in their study were able to progressively develop more sophisticated concepts of proportional reasoning as they developed mathematical models to represent proportions in the human body.

As discussed above every piece of research in mathematics education has underlying epistemological assumptions. This section has highlighted those papers that explicitly discussed some aspect of these epistemological assumptions within the paper. It has not been our intent to replicate the discussion of these papers elsewhere in this volume, as no doubt most will inform the discussion in subsequent chapters. However, we have attempted to show how the explicit epistemological perspectives in those papers influence the research frameworks and priorities within the research.

7 Conclusion

Our philosophical gaze has moved from a general overview of the keywords in more than 100 Australasian mathematics education research papers published between 2012 and 2015 to a more in-depth themed analysis of a purposive sample of 26 of these papers, to a detailed analysis of those papers that explicitly discuss epistemological aspects of the research. What stands out in our reading of the literature is that, with the exception of epistemology, the five philosophical dimensions discussed at the beginning of this chapter are largely unremarked. This does not mean that they are absent; rather most research papers implicitly assume particular positions relating to the nature of reality, how knowledge is produced, and issues of aesthetics, ethics or logic.

We have also identified a number of tensions inherent in the approaches embedded in the literature. At the beginning of this chapter we asked how we, as mathematics educators, choose between competing views of the world. The competing views we have identified include, for example, mathematics as a human construct or a model of reality, knowledge or beliefs as individual or social, mathematics learning as conceptual or procedural, research as interpretive or transformative, and curriculum as given or open to critique. We suggest that none of these tensions is one or the other. Rather, we suggest that mathematics education research (and hence education itself) is always both.

Thus rather than regarding these tensions simply as "wicked problems" (Adam & Chigeza, 2014), we suggest that mathematics education researchers and teachers have to live with them and use them as a creative force. When we, as mathematics education researchers, recognise and live with such tensions we do not become hostage to a particular view of the world, nor do we become blind to the underlying assumptions about the world that drive our work. Rather we recognise that research is underpinned by particular views of the world and the nature of knowledge, and that this has significant implications for both research and practice. We hope that the philosophical gaze adopted in this chapter provides a vehicle for identifying and questioning these underlying assumptions, and that it might provide the stimulus for ongoing philosophical inquiry within the Australasian mathematics education research community.

Appendix 1: Template Used in a Hermeneutic Reading of a Mathematics Education Research Paper

Paper: Fielding-Wells, J., Dole, S., & Makar, K. (2014). Inquiry pedagogy to promote emerging proportional reasoning in primary students. *Mathematics Education Research Journal*, *26*(1), 47–77.

Dimension	Observations
Ontology (metaphysics)—the nature of being, becoming, existence, or reality. What aspects of mathematics education are "taken as given" in the research? What do different research paradigms or theoretical frameworks used in the research assume about the nature of reality?	Maths is there "proper concept" (p. 48) Real life context crucial, mathematisation (p. 59), reasonableness (p. 69), transfer Challenges image of maths as unproblematic (p. 62)
Epistemology—the study of knowledge and justified belief and how we come by it. Are different views of knowledge evident in the research? If so, how do these epistemological positions impact upon the methods and outcomes of the research?	Student learning is "foundational" (p. 47), "developmental" (p. 48), "prerequisite" (p. 48), "difficulties with proportion" (p. 70) Maths as hierarchical, structured, sequential challenged (p. 50) Also p. 62—complex problems simultaneous with conceptual development (cf traditional approach). Challenge curriculum (p. 73)
Aesthetics—judgement about matters of value. What values appear to underpin the research and how do they impact upon the positions adopted by the researchers with respect to curriculum or pedagogy?	Efficiency, applicability, elegance, decision making, justification, analysis Affective and intellectual challenge and goals (p. 71) "Value mathematical practices that cut across particular content" (p. 55) Social impact (body image, Barbie), perhaps unstated
Ethics—systematising, defending and recommending concepts of right and wrong conduct. How does the research embed or contribute to moral or intellectual virtues such as truthfulness, impartiality, open-mindedness, courage and justice?	Goals to develop problem-solving, application, thinking tool Ill-structured better than well-structured Evidence stressed by children Philosophical approach to teaching (inquiry and epistemic argumentation) (p. 54) "Intellectual rigour", "authentic practice", "investigative spirit", "ownership", "accountability" (in the group learning sense) (p. 70) "Scrutinise role of mathematics as gatekeeper" (p. 71)
Logic—the use and study of valid reasoning. What different approaches to reasoning or argumentation are used in the research? How do these different approaches position the research with respect to its capacity to be generalised or contextualised?	Enquiry, evidence (p. 72 and following)—Geneva's story, public argumentation Frameworks to summarise process Question, evidence, conclusion, purpose (p. 53) Modeling with unifix cubes Norms

Appendix 2 List of Papers Used in Hermeneutic Reading of Mathematics Education Research Papers

Chapter numbers	Keywords used to search for papers	Papers used
Chapter 4	Policy, curriculum, leadership	Sullivan, Clarke, Clarke, Farrell, and Gerrard (2013), Zhang and Stephens (2013)
Chapter 5	Affect, affective, attitudes	Attard (2013), Lim and Chapman (2015)
Chapter 6	Equity, diversity, social justice	Averill (2012), Lange and Meaney (2014)
Chapter 7	Inclusive, disabilities, special needs, gifted	Bicknell and Riley (2012), Faragher and Clarke (2013)
Chapter 8	Indigenous, second language, Maori, Torres Strait Island, Aboriginal	Meaney and Evans (2013), Owens (2015)
Chapter 9	Early years, early childhood, pre-school, prior to school, young children, babies, toddlers	Cohrssen, Church, and Tayler (2014), Gervasoni and Perry (2015)
Chapter 10	Tertiary, university, undergraduate	Barton, Oates, Paterson, and Thomas (2015), Thomas and Klymchuk (2012)
Chapter 11	Innovation, pedagogy, problem solving, transformative	Ho and Lowrie (2014), Pierce and Stacey (2013)
Chapter 12	Assessment, evaluation, testing, standards, formative, summative	Logan (2015), Roche and Clarke (2013)
Chapter 13	Digital, media, computers, devices, tablets, apps	Calder (2012), Muir (2014)
Chapter 14	Mathematical applications, mathematical modelling, real world, mathematising	English (2012), Stillman and Brown (2014)
Chapter 15	Pre-service, initial teacher education	Anthony et al. (2015), Cavanagh and Garvey (2012)
Chapter 16	Professional learning, community of practice, teacher-development, early career	Goos (2014), Wilkie (2014)

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