A Review of Recent Research in Early Mathematics Learning and Technology

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The proliferation of technological tools in Australian mathematics classrooms has not been well supported by evidence-based research, particularly in early mathematics learning. This paper reports two stages of document analysis; a review of recent meta-analyses in early mathematics education and technology, and a quantitative analysis of research published in selected mathematics education research journals over the last five years. The initial review highlights potential affordances of technology for mathematics learning predominantly with older students. The quantitative analysis supports this finding but highlights the limited quantity and scope of publications focused on mathematics learning and technology with young children.

Technology has been lauded as a potential tool to improve mathematics learning; and technological tools, in all forms, are becoming more prevalent in many Australian classrooms. Lynch's definition of technology is utilised here to incorporate all "electronic computing media" (2006, p. 30). The theoretical framework of Hoyles and Noss (2003) centres on the impact of digital technologies that have the potential to alter and enhance students' cognitive infrastructure. There is a growing research field that investigates the advantages of technology use to enhance mathematics learning (Gutiérrez & Boero, 2006). While studies on the use of technology in mathematics learning have explored the pedagogical ramifications and outcomes for older students, few studies have examined technology use in early mathematics education. Perry and Dockett (2007) describe a recent surge in early childhood mathematics education research. However, other reports assert that there is an absence of studies focused on the role of technology (Groves, Mousley, & Forgasz, 2006; Mulligan & Vergnaud, 2006; Perry & Dockett, 2004).

This paper originated from a review of recent, pertinent, international journal articles that examined the impact of technology in early mathematics learning and repeated claims lamenting a paucity of research in this area (Clements & Sarama, 2003; Yelland, 2000, 2005). Research in early mathematics learning and technology is scant and so judgements about potential affordances in mathematics instruction are, to a large extent, purely speculative. This paper seeks to quantify and systematically account for the proportion and scope of articles dedicated to early mathematics learning and technology, profiled in international mathematics education journals, as identified by Australian researchers. This review aims to inform the design and scope of further research in this area, and to situate Australasian research within an international context.

Previous Reviews

An analysis of several previous reviews of research in early childhood mathematics education, educational technology in early learning and/or early mathematics learning with technology highlight three recurring themes: (i) calculator use and effectiveness, (ii) computer use and effectiveness and (iii) research in early childhood mathematics learning.

1. Calculator Use and Effectiveness

There is a significant corpus of research devoted to exploring the implementation and effectiveness of sustained calculator use on early mathematics learning (Groves et al., 2006; Perry & Dockett, 2004). A surge of Australian research has documented the potential for calculators to allow profound changes in teaching and learning mathematics. However, more recent research has suggested that studies of actual classroom implementation are limited (Groves et al., 2006). Scrutiny of previous meta-analyses suggests that the initial euphoria surrounding calculator use has not been sustained, as the most recent study cited in Groves et al. (2006) was conducted in 2000.

2. Computer Use and Effectiveness

A common theme emerging from meta-analyses examining technology use and mathematics is the crucial role of the teacher and accompanying pedagogy which support effective technology integration (Groves et al., 2006; Laborde, Kynigos, Hollebrands, & Strasser, 2006; Yelland, 2005). Regardless of the technology

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used, appropriate teacher intervention has been consistently identified as an essential element for successful mathematics learning. It has been suggested that technology, per se, does not improve student learning. It is the curriculum in which it is embedded, and the accompanying pedagogy, which may determine the ultimate effectiveness of technology implementation in mathematics classrooms.

Screen-based tools such as Logo, Microworlds and dynamic geometry environments have been identified as applications in which there has been significant research in mathematics education (Ferrara, Pratt, & Robutti, 2006). These tools afford representational expression and shape mathematics learning, but there are few studies that describe the representational processes of young learners. Plowman and Stephen (2005) echo this shortcoming in existing research, sighting that much of this work is confined to screen-based technology. Most studies have examined the role of screen-based tools with students in elementary and secondary school but there are few studies with younger students.

Previous reviews of research, examining the use of technology in mathematics learning, have been limited in scope to particular mathematics domains. It appears that geometry, algebra and calculus have been well researched as domains exploiting the potential affordances of technology. These studies suggest technology may have a positive impact on student learning outcomes in specific domains (Laborde et al., 2006; Yelland, 2005). However, these meta-analyses and reviews have not articulated whether technological tools may also enhance learning outcomes in other mathematical areas such as rational number and measurement.

Computer games have also been identified as potential tools for enhancing mathematics instruction (Perry & Dockett, 2004). The permeation of educational software and web-based resources designed specifically for mathematics instruction is striking, yet there is a notable absence of studies which evaluate the impact of this software on early mathematical learning. Research is required to review the range of software applications used in classrooms and to assess their effectiveness in capturing and conveying mathematical content (Groves et al., 2006). New technologies, particularly games-based environments, may alter learning trajectories for young learners, but research has not validated this claim (Perry & Dockett, 2004).

3. Research in Early Childhood Mathematics Learning

The reviews of research, specifically related to early mathematics learning, are dominated by studies exploring the domain of numeracy. There are a plethora of studies, in Australian and New Zealand, documenting the implementation of systematic numeracy initiatives with young learners, such as Count Me In Too and First Steps (Perry & Dockett, 2004).

These reviews continue to indicate that the use and impact of technology in early mathematics learning does not appear to have been a widely researched area (Fox, 2007; Groves et al., 2006; Mulligan & Vergnaud, 2006; Perry & Dockett, 2004, 2007). This is despite an overall surge in early childhood and neuro-scientific research, with recent policy and curricula reflecting the view that young children are capable learners (Clements & Sarama, 2007a; Fox, 2007). In summary, previous meta-analyses and reviews conclude that further research is needed to explore the role of technology in young children's development of mathematical concepts.

Method

The first stage of this document analysis involved an evaluation of previous reviews and meta-analyses of mathematics education research published within the last five years. Common themes were identified and are summarized in the preceding section. The second stage comprised an analysis of research published in five international mathematics education research journals over the same time frame (January 2003-November 2007). The five journals selected were for analysis were identified by Australian mathematics researchers as significant The five significant mathematics education research journals selected for analysis were: 1) Educational Studies in Mathematics; An International Journal; 2) Journal for Research in Mathematics Education; 3) For the Learning of Mathematics; An International Journal of Mathematics Education;4) Mathematics Education Research Journal (Journal of the Mathematics Education Research Group of Australasia Inc.); and 5) The Journal of Mathematical Behavior.

The authors chose to investigate only those articles published during the last five years from each of these journals, both to ensure currency of research and for pragmatic reasons. The five-year span also enabled any emerging trends and current developments in technology use to manifest.

Three phases of analysis allowed articles to be systematically examined and categorized (editorial comments, book reviews and letters to the editor were not included). The first phase of analysis focused on each journal index separately and then sorted articles by title, abstract and keywords. In this phase, each article was categorized according to age group and whether technology was a focus. This enabled the researchers to compile a succinct list for further analysis in the second phase. The second phase of the analysis identified those articles that focused on early childhood education (in Australia, this is from birth to eight years). These were examined more closely for identification and coding of key mathematical concepts and processes. The third phase analysed those articles incorporating technology as a learning tool and identified the specific technologies employed in each study.

Discussion

The following section provides an overview of four key findings arising from the second stage of this analysis.

1. Age Group Categorization

In total, 512 journal articles were reviewed. Of these articles only seven (1.4%) investigated mathematical learning processes of children prior to school age. Another 34 (6.6%) articles included children in their first three years of school. However, of this group of articles 29 (5.7%) reported studies of children included in a larger cohort with older students as subjects of research. In relation to the entire body of articles those investigating mathematics learning of young children is disproportionately low (see Table 1) and warrants further investigation.

These findings confirm assertions made in previous meta-analyses (Fox, 2007; Groves et al., 2006; Mulligan & Vergnaud, 2006; Perry & Dockett, 2004, 2007) that research on young children's early mathematics learning is under represented. Other research (Baroody & Lai, 2005; Clements & Sarama, 2007) highlights increased emphasis on the fundamental importance of early mathematics learning; yet this is not reflected in the selected mathematics education research journals within the given time frame. It is possible that the publication of such research is disseminated in early childhood, technology education and/or generic education journals but this work was not prominent in either the current analysis or previous meta-analyses.

Table 1

Age group of participants represented in journal articles (n=512)

Age group of participants	Percentage of total (n=512)
Children prior to school (aged 0 - 5)	1.4%
Children in the first three years of school (aged 5-8)	6.6%
Children in the first three years of school (aged 5-8) as part of a larger cohort	5.7%
Children in the first three years of school (aged 5-8) as sole cohort	0.97%

2. Mathematical Content Domains

A review of the studies conducted with young children identified numeracy as the most commonly reported mathematical domain, supporting the finding of previous meta-analyses (Mulligan & Vergnaud, 2006; Perry & Dockett, 2004, 2007). These studies focused on cardinality, counting, number concepts, addition, subtraction, multiplicative thinking and rational number. Another frequently reported area of investigation related to teaching, curriculum and/or assessment issues. A third domain frequently discussed was problem solving. The focus on curriculum and problem solving is in contrast to the findings of previous reviews (Yelland, 2005). Other themes evident, albeit limited in frequency, include generalized mathematical processes, mathematical language and discourse analysis, and spatial and geometry concepts. Of concern was the lack of research investigating young children's use of technological tools in mathematics teaching and learning. Whilst these findings may reflect the emphases of the particular journals and/or the agendas driving international policy and curriculum reform, it is clear that a wider range of studies is needed.

3. Technology in Mathematics Education Research

Of the 512 articles, approximately 10% (n=51), identified educational technology as a focus of investigation. These data represent varied groups and only a few (n=4) relate solely to research with young children. These four articles described the potential affordances of screen-based technologies such as Building Blocks (Clements & Sarama, 2007b), the Ameritech Classroom (Davis & Hyun, 2005), graphical application software (Åberg-Bengtsson, 2006) and a technology games-based environment (Lowrie, 2005). An analysis of the types of technology indicate a dominance of screen-based software, a finding which is consistent with the work of Plowman and Stephen (2005). In these journals thirty-nine of the 51 articles with a technology focus utilized screen-based technologies. These studies predominantly dealt with older students. This perpetuates the trends evident in previous reviews where older students were the focus of research (Ferrara, Pratt, & Robutti, 2006; Laborde et al., 2006). These focus areas included but were not limited to, Geometer's Sketchpad and other dynamic geometry programs, graphing software, spreadsheets, computer-algebra systems (CAS) and web-based resources. Eleven of the articles specifically investigated the use of calculators with a dominance of research on graphic calculator use. This may be attributed to the rising popularity and affordability of these tools.

4. Trends Over the Five-year Period

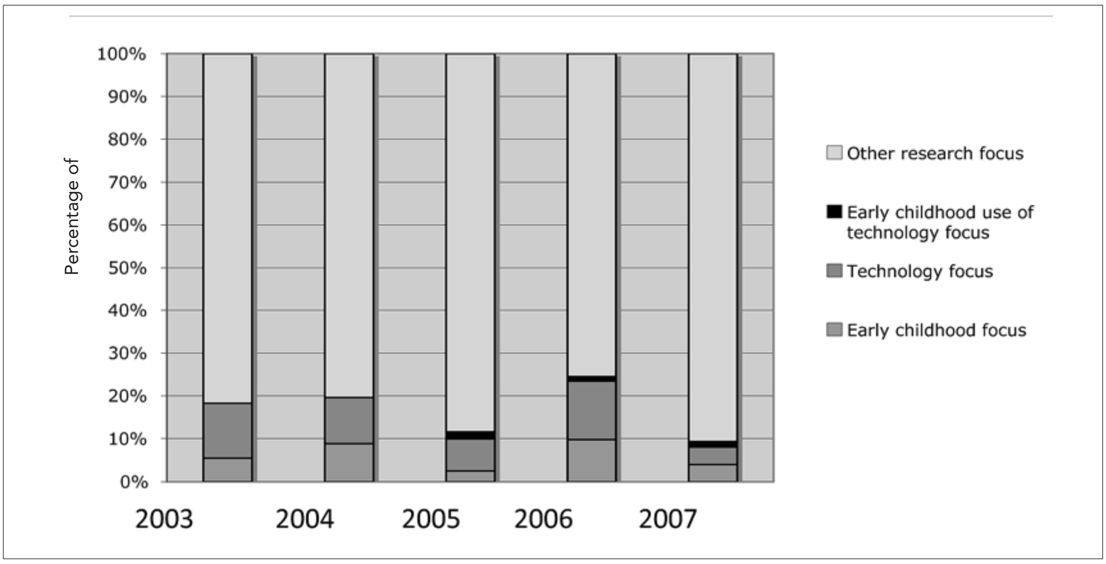

Figure 1: Percentage of articles published in selected mathematics education research journals with an early childhood and technology focus.

Whilst, as suggested by Perry and Dockett (2007), there is some growth in research that focuses on young children's mathematical development and technology, these results suggest that it would be premature to propose any emerging trends over the period investigated in these journals. Figure 1 (above) shows the proportion of articles pertinent to early mathematics learning with technology. Again, these articles utilized screen-based technologies, corroborating findings from previous reviews (Ferrara et al., 2006). It is promising to note that there has been some research published in this area over the last three years. In Australia, there is currently a strong government agenda resulting in the rapid implementation of technological tools in classrooms. However, this agenda is not supported by a sufficient research base.

Conclusions, Limitations and Implications for Further Research

This review is limited by both the number of journals selected for review and the subjective nature of selection. The identification of these significant journals by Australian mathematics education researchers is to some extent subjective. Further, the exclusive selection of articles published in English limits the breadth of investigation. The time frame for analysis was the recent five-year period and any pertinent articles or emerging trends prior to this were omitted from the second stage of analysis.

It is clear from these data that there is a shortage of research pertaining to young children's mathematics in the selected journals, which is even more pronounced when technology is the modality for learning. However, despite these findings it is not possible from these data to accurately speculate on the reasons behind this paucity. A review of the broader research corpus in early childhood does provide some insight and suggests that there may be several factors that may account for this lack of published research. It is plausible that research investigating the use and effectiveness of technology in early mathematics learning has been conducted, but published elsewhere. There are multiple avenues for research of this nature to be published: results may have been disseminated in early childhood journals or technology journals. A proposed, expanded review of journals would confirm or reject this postulation. Broadening the present analysis to include early childhood journals and technology education journals will provide opportunity for a fuller review and potentially insight into the reasons behind the limited research in this area.

It is also possible that the absence of articles pertaining to early mathematics learning and technology may be a direct result of a lack of research being conducted in this area. There has been an historical reluctance in the early childhood field to embrace digital technologies and this has translated in the disappointing uptake of technology in prior-to-school settings and the early years of formal schooling (Cordes & Miller, 2000; Dwyer, 2007). If the available technologies are not being harnessed in classroom settings, then it is unlikely that research would be conducted on their use. This is surprising for two reasons: first, technological tools are permeating schools and to a lesser extent, prior-to-school facilities and second, the early years have been identified as a crucial stage of learning. There is a growing body of empirical research which clearly delineates the importance of the early years in terms of cognitive development (Aubrey, Dahl, & Godfret, 2006; Ginsburg, 2002) and studies suggesting that young learners are capable and competent mathematicians (Baroody, 2004; Perry & Dockett, 2002). Perhaps, one of the difficulties faced by researchers is the limited opportunity to engage in investigations with young children who are using technological tools in naturalistic settings. Young children may also be reluctant to articulate their thinking when they are focused on activity with technological tools.

In summation, an analysis of the selected mathematics education research journals provides quantitative evidence to support claims that there is a paucity of research examining early mathematics learning with technology. At an international level this is reflected in previous meta-analyses and echoed by publications of the PME group (Mulligan & Vergnaud, 2006). These findings have implications for both research development and dissemination in early mathematics education. The analysis calls for new research agendas and supports current work conducted at the Centre for Research in Mathematics and Science Education (CRiMSE) at Macquarie University. Here, a suite of new studies on young children's early mathematical development and the use of technology, such as programmable toys, dynamic interactive software and interactive whiteboards, are in progress.

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