A Framework for Examining Technologies and Early Mathematics Learning

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Background

Over the past decades there has been increased impetus to use technology in early childhood learning settings (Clements and Sarama 2002; Edwards 2005; Haugland 1997, Plowman and Stephen 2003, 2005; Yelland 2010). In addition, there is a wealth of new technologies and interactive multimedia and technology resources available for mathematics teaching and learning. However, research is yet to articulate and substantiate their use and impact on student learning (Highfield and Goodwin 2008).

In mathematics learning visual representations are essential for communicating ideas and concepts (Goldin and Kaput 1996) and new technologies offer new affordances for representation (Highfield and Mulligan 2007; Moyer et al. 2005). Advances in interactive multimedia and manipulable technologies provide learners with the opportunity to view and manipulate dynamic media and share external representations with ease. In mathematics, studies have established that computers provide "unique opportunities for learning" (Clements 2002, p. 174) and provide "greater scope to facilitate numeracy skills in young children." (Kilderry and Yelland 2005, p. 113).

Over the last decade there has been an exponential growth in the educational multimedia market, with a plethora of interactive technologies available for mathematics learning and teaching such as interactive whiteboards, educational software, iPads and robotics. However, as outlined above, the ubiquitous application of interactive representations in mathematics has not been well supported by a corpus of

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L.D. English, J.T. Mulligan (eds.), *Reconceptualizing Early Mathematics Learning*, Advances in Mathematics Education, DOI 10.1007/978-94-007-6440-8_11,

research to substantiate their effectiveness, particularly in early mathematics learning. There has been an assumed sense of superiority of interactive technologies, without a corresponding corpus of evidence supporting their cognitive value (Scaife and Rogers 1996).

In considering screen-based resources (interactive multimedia), it is unknown as to whether different pedagogical designs evoke qualitative differences in the kinds of representations students internalise. Little is known as to what students extrapolate from various dynamic, interactive on-screen representations. With some multimedia, learners often have to coordinate multiple and diverse representations, placing various demands on their cognitive infrastructure. This does not necessarily lead to better learning and may actually hinder students' learning outcomes. Screen embellishments and animations may also impose unnecessary additional cognitive demands on the learner. With other multimedia forms, the onus is on the students to develop their own multimedia representations, which requires a significant cognitive investment on each learner's behalf. Students may not engage with the representations in ways conducive to learning but instead, they may engage in superficial processing (Rogers and Scaife 1998).

Further, the impact of different multimedia designs on learning remains largely un-researched and this problem is further pronounced with young learners, where there is even less research. A systematic examination of the potential affordances and impact of the available mathematical multimedia on young students' learning is required to identify various multimedia attributes for mathematics learning. It is widely accepted that humans have a limited working memory (Baddeley 1986), thus instructional representations must be designed with the goal of reducing extraneous cognitive load. Multimedia design principles must be commensurate with how learners perceive and interpret the information presented to them on-screen.

The past decade has seen an increasing body of research on the application of screen-based technologies for mathematics teaching and learning (Clements and Sarama 2009; Heid 2005; Plowman and Stephen 2005; Zevenbergen and Lerman 2008). However, a significant proportion of that research examines screen-based tools (Highfield and Goodwin 2008) and the same depth of research is not present in mathematics learning with techno-toys. This means that in addition to the concerns outlined with interactive multimedia there are an increasing range of alternate technologies, such as simple robotics and techno-toys that provide alternate experiences with technologies. These additional tools may provide unique opportunities for mathematics learning, or indeed may add to the complexity of the technological and pedagogical landscape for young mathematics learners.

One specific example of an alternate technology is simple robotics. To date the research available on the role of programmable toys in mathematical development is restricted and often focuses on older children, with limited studies investigating their role in young children's mathematical learning (Janka 2008; O'Meara 2011; Stoeckelmayr et al. 2011). Additionally, it appears that this limited research has not been disseminated in such a way as to impact upon the professional practice of early childhood educators (Clements and Sarama 2004; Edwards 2005; Waters 2004).

It is clear that further research is needed to investigate the impact of technology in mathematics learning, with a focus on a broad range of technologies including screen-based interactive multimedia and manipulable toys such as simple robotics.

Studies on Early Mathematics Learning with Technology This section provides an overview of four studies conducted by the two authors (Highfield and Goodwin) as part of early research (Highfield and Mulligan 2007), their PhD theses (Goodwin 2009; Highfield 2012) and current research project (Goodwin and Highfield 2012). Each of these studies examined key technologies appropriate for early mathematics learning. Goodwin (2009) and Highfield (2012) both focus on the use of children's representation as evidence of mathematics learning. This section presents a brief overview of these studies, with exemplars from these projects provided.

Goodwin's (2009) study investigated young students' (aged five to eight years) use of a variety of interactive multimedia to develop their concepts of fractions. A classification scheme and taxonomy of interactive multimedia was established. Three classes of multimedia were grouped according to the ways in which the students interact with the representations: (i) instructive multimedia; (ii) manipulable multimedia; and (iii) constructive multimedia. With a specific focus on the impact and affordances of the three different types of multimedia on young students' concept image of fractions, the study also focused on how learners at the extremes of mathematical achievement used and responded to the multimedia.

Goodwin's (2009) design-based research study amalgamated a constructivist teaching experiment and a case study approach. The study was comprised of two iterations, involving a total of 86 students from three Kindergarten (the first year of formal schooling) classes and a Year One (the second year of formal schooling) class. Both iterations examined the influence of an intervention employing the three different types of interactive multimedia previously listed. Iteration One involved one Kindergarten and one Year One class who participated in a four-week intervention and constituted a pilot study for the next iteration. Iteration Two involved two Kindergarten classes: an intervention class and a comparison class, in which a 12-week intervention was implemented. Data sources included students' drawings collected before, during and after the intervention, a multimedia fraction assessment administered before and after the intervention, digital screen and audio recordings of students' computer work and video-stimulated recall interviews to ascertain students' recall of the multimedia content. Case study data from four students in each intervention class (two low-achieving and two high-achieving students) included digital screen recordings and video-stimulated recall interviews. A mixed method approach (Creswell and Clark 2007) to analysis was adopted, incorporating both qualitative and quantitative approaches. Innovative data analysis and reporting techniques were utilised to provide rich and authentic data to support the themes related to the impact and affordances of the interactive multimedia. Data analysis involved coding screen recordings and interview data using *Studiocde* software. Triangulating case study data from the analysis of post-lesson drawings, screen recordings and video-stimulated recall interviews provided a more complete description of phenomena and promoted greater reliability.

Results from Goodwin's (2009) study indicated substantial improvements in the intervention students' drawings and multimedia fraction assessments. All students in Iteration One showed improvements in terms of their concept image of a fraction, as projected at the post-intervention assessment point. In Iteration Two, the intervention students showed more advanced and sophisticated concept images of fractions than the non-intervention sample at three assessment points (pre-, during- and post-intervention). In both iterations the students' concept image of fractions developed between the pre- and post-intervention assessment points, becoming more sophisticated in terms of the level of structure, mathematical concepts and use of symbol notation. Intervention children, who used interactive technologies, could successfully depict multiple representations and showed evidence of advanced mathematical ideas such as non-unit fractions and equivalent fractions and counter examples after the intervention. Many intervention students' concept images also included alternative, 'non-schooled' depictions of fractions and increased use of formal symbol notation ah the post-intervention assessment point.

Goodwin's (2009) analysis of the intervention data documented differences between the three types of interactive multimedia in terms of the concept images projected. Analysis of post-lesson drawings suggested that the students demonstrated the most developed and advanced representations after using manipulable multimedia. There was a higher incidence of students' recalling idiosyncratic, superfluous and non-mathematical details and displaying 'crowded' images after using instructive multimedia and fewer, less developed representations generated when using constructive multimedia.

Throughout this work, case study data corroborated findings from the intervention data that suggested that manipulable multimedia had the greatest impact on students' concept image. Each classification of multimedia offered distinct affordances in terms of the frequency of the representations the students observed or created, the ease of experimentation with the representation and the levels of student engagement. The importance of the provision of instant feedback and evidence of multimedia design principles were also reflected in the case study data.

A standardised mathematics assessment, *I Can Do Maths* (Doig and de Lemos 2000), was administered to before the intervention to identify 'high-' and low-achievers'. This enabled the researcher to determine if high- and low-achievers used and responded to interactive multimedia in different ways. Differences were also noted between how the low- and high-achievers used the multimedia and recalled what had been presented. The low-achievers had a greater tendency to focus on the superfluous and surface details embedded in the multimedia resulting in superficial processing of the multimedia. In contrast, the high-achievers were adept at selecting the salient information from the multimedia to construct effective mental models.

The second study, by Highfield (2012) examined a manipulable form of technology: simple robotic toys (Bee-bots and Pro-bots). This work was pertinent, given the ubiquity of young children's engagement in technology and consistent research focus on screen-based tools. These programmable toys offer tangible interactions and provide opportunity for young learners to engage in a range of mathematical concepts and processes as they input, execute and reflect upon programs. This study focused on young children's engagement, representation and dynamic manipulation of tools as they engaged with these toys in play and teacher directed tasks.

Highfield's (2012) study followed 31 children, aged three to seven years as they engaged in a twelve-week program in their classroom environment. Children from two contexts participated, a prior-to-school setting and a nearby primary school, with three groups of children: Three-year olds, Four-year-olds and a Year One class. Each group of children completed five phases of the study, including pre- and post-interviews, a training session at the Macquarie ICT Innovations Centre, and a sequence of teaching and learning episodes.

This work also drew on design-study methodology (Gravemeijer and van Eerde 2009) and adopted multiple layers of analysis, with children's mathematics learning examined through video data of classroom engagement and play and through drawn representations. Video data were analysed to explore children's use of gesture, action, dialogue and representations of programming. A multi-faceted theoretical approach exemplified the interconnection between the development of semiotic systems, incorporating speech, gesture, embodied action and representation of dynamic concepts.

Highfield's research highlighted the affordances of simple programmable toys in mathematics learning and problem solving. Data indicated that children explored a range of mathematical concepts and processes including number, unit iteration, estimation, angle and geometry concepts. Further, children engaged in meta-cognitive processes integrating planning, prediction, observation, reflection and revision as components of problem-solving. Children's strategy use in these tasks, such as acting out with the toy and using symbols and gesture, provided insight into emergent mathematical thinking.

A third study examined screen-based resources with a specific focus on virtual manipulatives, such as those available through the National Library of Virtual Manipulatives (accessible through http://nlvm.usu.edu/). Highfield and Mulligan's work (2007) examined how web-based tools provide a unique representational opportunity, creating a dynamic, virtual representation of a concrete material. This small-scale study explored virtual manipulatives and open-ended drawing software as tools in mathematical patterning with pre-school children.

This research was conducted as a constructivist teaching experiment, (Hunting et al. 1996) with three dyads of preschool children, aged between four and five years. Integrating elements of design study, this approach allowed for teaching episodes to be constructed and scaffolded systematically, with revisions occurring based on children's progress and engagement with pattern-eliciting tasks. Each dyad was assigned to one of three learning modalities using: concrete materials (such as blocks, counters, animal pictures, stamps, paint, pencils); a combination of concrete materials, dynamic interactive software (Kidpix) and virtual manipulatives (virtual Pattern Blocks); or, dynamic interactive software (Kidpix) and virtual manipulatives (Pattern Blocks). Once allocated a modality, children completed six, 40-minute teaching and learning episodes, conducted by the researcher over a 4-week period. Children engaged in pattern-eliciting tasks such as making wrapping paper, with tasks and resources matched so that comparison between traditional modalities and technological tools was possible.

Within this project Highfield and Mulligan (2007) demonstrated young children's ability to develop skills in simple patterning over the four-week period, with no significant differences evident when comparing children's patterning skills while using traditional materials or technological tools. Data did however indicate that children were motivated to engage with the dynamic interactive software and virtual manipulatives when patterning. Extended engagement with technology meant that children using technology were more likely to experiment with representations, creating an increased number of patterns and transformations when compared with children using concrete materials. In addition, the technological tools enabled increased representational detail and accuracy.

The final study presented within this chapter was conducted by both authors, Goodwin and Highfield (2012). This work examined Apps for learning, and was pertinent given the increasing popularity of touch devices such as iPods and iPads. At present there is a preponderance of Apps for these devices that are designed for young children and are marketed as 'educational'. Currently, there appears to be no review process involved in classifying Apps as 'educational' and as a result many Apps are strategically placed by developers in the lucrative 'Education' section of the iTunes App Store by developers. However, despite the plethora of Apps currently available for young children, research has failed to keep pace with the growth in this technology, with limited systematic analysis of educational Apps and those designed specifically for young children. This research project outlined a content analysis of the paid Apps that are currently available in the 'Education' section of the iTunes App Store. The findings of this study provided key information for both parents, teachers and App developers in the selection, use and design of Apps.

Within this study Goodwin and Highfield (2012) conducted an analysis of the "Top Ten" paid Apps located in the 'Education' section of the iTunes App store at four different points in time (six-monthly intervals) from April 2010 to October 2011. Data were obtained for three countries: United States of America, United Kingdom and Australia and Apps ($n = 360$) were coded using the following characteristics: age, subject area and classification of pedagogic design. In 2012 (Highfield and Goodwin under review) these data were revised to include two additional collection points, increasing the analysis to be over six intervals (April 2010 to October 2012).

In findings that were similar to Shuler's work (2012), Goodwin and Highfield's (2012) analysis, revised for this chapter, found that 29 % of the top ten Apps were designed for toddlers, 24 % for elementary children 13 % for secondary education. This study aggregates data for all three countries and shows a large proportion (34 %) were classified as 'Multi-age' with the App classified as suitable for a wide age range of students such as preschool and elementary children. Classification by content presented demonstrated the areas of Literacy (21 %) and Science (19 %) as the most common subject areas represented in Apps analysed, with Apps addressing multiple curriculum areas (such as numeracy and literacy) representing 18 % of the content. While many Apps embed mathematical processes, such as scoring and problem solving in game play, Apps that focus on this key area appear under-represented in the 'Education' section, with only 15 % focusing specifically

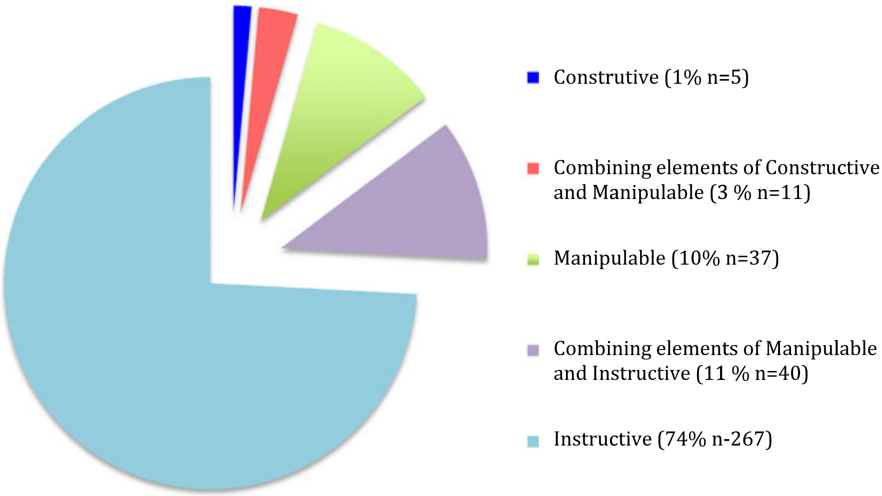

Fig. 1 An analysis of the "education" section of the App store, classifying Apps by pedagogic design (April 2010 to October 2012)

on mathematical content. Creative Arts are also limited in the 'Education' classification with only 6 % of Apps classified as focusing on this curriculum area.

Data analysis classifying Apps by pedagogic design affords pertinent data, highlighting a predominance of "instructive" Apps, with 85 % of 'Educational' Apps classified as Instructive, or as combining Instructive and Manipulable design pedagogies. Of particular note is the limited presence of Constructive Apps in the 'Education' classification. Here only 4 % of Apps were classified as Constructive or Constructive/Manipulable. Figure 1 provides a visual overview of analysis of popular 'education' Apps by pedagogic design.

Additional analysis indicates that these Apps are available in other sections of the App Store such as 'Apps for Kids' or 'Entertainment', rather than classified as 'Education'. This classification is intriguing and perhaps implies a diminished understanding of the educational potential of open-ended learning and representational tools.

Re-framing Current Research Using Analysis by Pedagogic Design

While each of these studies present could be seen to outline disparate examples of current research each can be re-framed as having unique affordances for mathematics learning when re-conceptualized in light of their pedagogic design. The following section outlines current classifications of educational technologies and then outlines Goodwin's (2009) classification of educational technologies.

Numerous authors (Clements and Nastasi 1992; Handal and Herrington 2003; Hosein et al. 2008; Hoyles and Noss 2003; Sarama 2003) have presented taxonomies that classify various types of educational software. However, there appears little consensus as to the most appropriate classification scheme. This is further compounded by the fact that many of the classification schemes and taxonomies become irrelevant as the technologies they were describing developed, become more complex or were superseded by technological developments.

Previous classification schemes have not taken into account how different tools encode and display mathematical ideas in different representational forms. Thus, most of the existing taxonomies and classification schemes have focused on the functionality of the software in terms of what the learner can do with it (Kurz et al. 2005). Students interact with different multimedia representations in distinctive ways to make sense of and integrate the representations into their cognitive infrastructure (Sedig 2004). In fact, there are no known frameworks that systematically analyse the way in which multimedia representations are designed and how their design impacts on students' understanding of the representations.

Whilst multimedia tools have shown the potential to improve mathematics learning (Atkinson 2005; Sedig et al. 2003; Clements et al. 2008), there does not exist any systematic way of classifying how learners engage with mathematical, multimedia representations. Scaife and Rogers (1996) highlight the paucity of research on the cognitive value of representations, especially those contained within multimedia applications. Given that different types of multimedia exist, as the previous classification schemes have identified (Handal and Herrington 2003; Kurz et al. 2005), a prescriptive taxonomy would help to identify how learners interact with and respond to different multimedia. Scaife and Rogers (1996) call for a systematic approach to evaluate the merits of different types of on-screen representations, with an explicit focus on how students cognitively interact with them. This would assist multimedia designers develop appropriate interaction techniques and design characteristics in future products. It would also enable teachers to design appropriate learning activities to complement learning experiences with multimedia.

A Classification of Interactive, Mathematics Multimedia for Young Learners

The classification scheme presented in this chapter specifically describes, classifies and seeks to evaluate mathematical multimedia, with the particular focus of analysing the instructional design considerations in relation to the way the representations are presented to the learner. The genesis of this scheme was to overcome limitations of previous taxonomies, by describing the unique affordances of different interactive multimedia. Whilst this evaluative framework was established to analyse the available multimedia specifically designed for young learners, the framework could be equally applied to multimedia designed for older learners and, possibly, disciplines other than mathematics.

Three broad classifications of interactive multimedia are proposed, as exemplified by Fig. 2: instructive, manipulable and constructive multimedia. This scheme

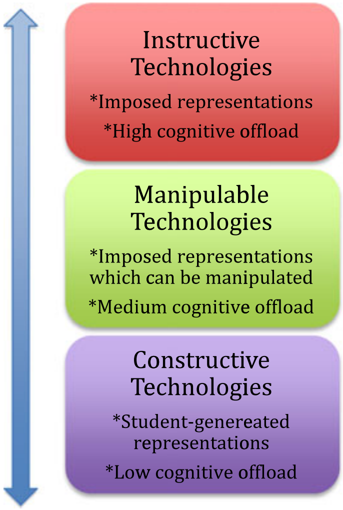

Fig. 2 A continuum of the pedagogic design of interactive technologies

extends the theoretical perspectives in the field of learning with interactive multimedia, by presenting a framework that can be applied to a range of digital technologies and interactive media. The classification scheme is based on the design features of the interactive multimedia, with a particular focus on the learner's locus of control over the representations presented on screen. The classification scheme also considers the type and level of cognitive demand and interactions afforded by the multimedia. The lines of demarcation between each of the classifications presented in Fig. 2 are not fixed. The classification scheme does not suggest that one design approach is superior to another as each particular representational mode has unique utilitarian functions that may be suitable at different stages of the learning cycle. Exemplars, arising from the aforementioned studies, are presented for each of these classifications and are detailed in the following sections.

1. Instructive Technologies At the top of the continuum in Fig. 2, are applications that are classified as instructive. These applications are based on a behaviourist theory of learning that assumes that knowledge can be directly transmitted to the learner. Such applications rely on reward, repetition, regular review and feedback loops and contingent increments of difficulty to teach various skills (Atkins 1993). Representations of concepts are essentially imposed on the learner. These tools promote procedural learning and are based on the philosophical assumption that knowledge can be presented symbolically and learned in a linear fashion. The learners perceive messages encoded in the medium and sometimes interact with the technology (Jonassen 1994). A fundamental tenant of this type of software is that an "expert", the designer constructs the screen representations that are presented to the student. Software applications adhering to this classification, base their learning experiences on a stimulus-response-reinforcement model. Students are required to master and replicate knowledge through closed, pre-programmed learning tasks, usually using the stimulus-response format: the software is designed to compare student input with a pre-determined answer.

Drill-and-practice CD-ROMs are a prime example of instructive multimedia. These CD-ROMs elicit homogeneous responses from users via imposed tasks. The market for such educational CD-ROMs expanded rapidly in the 1990s and has recently stagnated because of the ease through which materials can be now disseminated on the Internet (Buckingham 2007). However, educational CD-ROMs are still a popular choice amongst educators and parents, particularly with younger learners where there is a prevalence of age-related CD-ROMs designed to meet curriculum standards. Described as "shovelware" (Buckingham 2007, p. 129), educational drill-and-practice CD-ROMs have been criticised for their attempts to "jazz up the curriculum with a superficial gloss of kid-friendly digital culture" (Buckingham 2007, p. 136). Interactivity is often superficial, limited to animated objects that can be activated by the learner clicking on an icon or reactive interactivity that results from the learner entering a correct pre-determined response.

In relation to the cognitive investment required by the learner, instructive multimedia generally demand the least amount of the learner's cognitive energy of the three classifications. Typically, the students assume a passive role when using instructive multimedia as they do not have to expend much mental effort to process the information conveyed on-screen. Interactivity is often restricted to surface level interactivity (Aldrich et al. 1998; Evans 2007; Inkpen 2001; Sedig and Liang 2008; Triona and Klahr 2003) such as clicking or dragging a correct response.

Exemplar of Instructive Technology One example used within Goodwin's (2009) study of instructive technology is Galaxy Kids. Maths: CD-ROM (Published by Sunshine Multimedia 2005). Differences were noted between how the low- and high-achievers used the various multimedia and recalled what had been presented. When using instructive technologies the low-achievers had a greater tendency to focus on the superfluous and surface details embedded in the multimedia, resulting in superficial processing of the multimedia. The inclusion of idiosyncratic details, such as actions and attributes of the on-screen character, referred to as an 'animated pedagogical agent' (APA) in children's representations were most frequent after using instructive technologies. In contrast, the high-achievers were adept at selecting the salient information from the multimedia to construct effective mental models of fractions, in this instance.

As exemplified by Figs. 3 and 4, the same student responded differently to various interactive multimedia. After the instructive technology "Hydroslide" (Galaxy Kids Maths CD-ROM), the student's post-lesson drawing (Fig. 3), included non-mathematical attributes such as the water slide and the APAs called "Digits". However, the same student's post-lesson drawing lacked evidence of an awareness of equal partitioning, despite this being the instructional focus of "Hydroslide". In contrast, the same student, at a later point in the intervention, completed the drawing shown in Fig. 4. This drawing was completed after the student had used the manipulable technology "Fraction Fiddle: Tool". Figure 4 reflects an understanding of equal-partitioning, formal symbol notation and a basic depiction of equivalent

Fig. 3 A student's post-lesson drawing of "Hydroslide" (instructive multimedia)

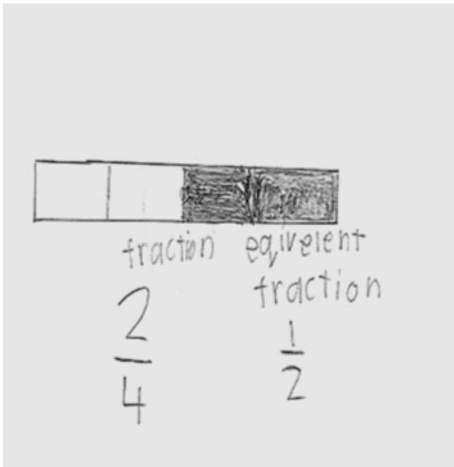

Fig. 4 A student's post-lesson drawing of "Fraction Fiddle: Tool" DLO (manipulable multimedia)

fractions. It is important to acknowledge that the two multimedia tasks described above, were focusing on two different concepts, which prevents any direct comparisons from being made. However, it appears that the manipulable technology, which was devoid of superfluous and irrelevant embellishments may have supported the learners' conceptual understanding. In contrast, the instructive technology, with its highly contextualised representations and the inclusion of animations, sound effects and characters, was less successful in supporting the development of fraction concepts.

The authors posited that the animations and characters contained within the instructive technology, may have detracted the learners' attention away from the embedded mathematical concepts within the CD-ROM. The learners, particularly the low-achieving students were hindered in their recall of mathematical features as their cognitive resources were directed towards processing non-essential information. These findings support the previous work of Mayer and Moreno (2002) and

Mayer (2001) who have also shown that the redundant use of embellishments compromises students' working memory and adversely impacts on their cognitive load.

Screen recordings from Goodwin's (2009) study also exemplified how young learners sought instant feedback provided by the APA in the instructive technology. Many of the students' verbalisations recorded whilst using the CD-ROM indicated that the students were noting the frequency of correct responses as demonstrated by the APA dancing or providing a 'thumbs-up' gesture. One student stated, "That's so cool. I got Number Cruncher [APA] to the net level. He's free. He can escape the dungeon." This particular child was focused on achieving the result of enabling the APA to complete the assigned task, but there was no discussion about the embedded mathematical content, which involved placing half the number of rocks into a container to catapult the APA to another level within the dungeon. In the video-stimulated recall interview this child was unable to explain what they had learned in the previous lesson, other than to recall how they had helped Number Cruncher.

Although this chapter only provides one example additional data in Goodwin's thesis (2009) enables the inference that the exclusive use of instructive technologies may not afford optimal mathematical learning for young students. Young learners need to identify the salient ideas and key mathematical concepts contained within instructive technologies through rich discourse with their peers and teachers after using these types of resources. It is imperative that teachers do not falsely assume that young children have mastered the mathematical content embedded in the instructive technology especially if there are other distracting elements.

2. Manipulable Technologies The second classification of software and interactive technology is termed manipulable technologies (Fig. 2). This type of manipulable technology allows for guided student discovery and experimentation, but within a pre-determined representational context. The symbolic and iconic images are often presented to the student, but these can be instantiated and altered on the screen by user input. Whilst the representations are pre-imposed on the student by an "expert", students have an opportunity to manipulate the representations and test new configurations and ideas. The availability of manipulative variables allows learners to interact with and gain meaning from the interactive tools. In this sense, the computer acts as a "hypothesis testing learning environment" (Kong and Kwong 2003, p. 138). The student must interpret and purposefully interact with the screen representations. These programs are more sensitive to students' partially formed mathematical responses and may allow for the development of alternative representations as they mediate the cognitive capabilities of the learner (Hoyles and Noss 2003).

The cognitive effort elicited by manipulable technologies is greater than applications classified as instructive multimedia, but possibly less than those tools within the constructive multimedia category. Manipulable multimedia may reduce the amount of cognitive effort required to generate a representation while allowing the learner to direct their cognitive energy and conscious attention towards understanding and internalising the mathematical representations on screen.

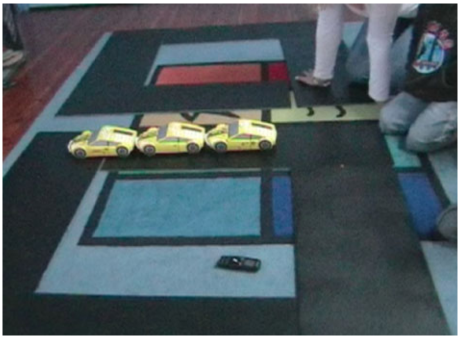

Fig. 5 Teacher using Pro-bots to measure the track in twin road task

Exemplar of Manipulable Technology Simple robotics present an example of manipulable technologies. Used throughout Highfield's (2012) work these tools offer a limited range of programming possibilities. In programming the robot the child must understand the available movements, the programming interface and then must enter a program. Children then often observe and reflect on the program, revising their attempts in a cyclic process. Here the manipulable tools are seen as promoting opportunity for reflection and revision of thoughts. Multiple semiotic systems used in processing and then representing movement provide insight into children's understanding.

In this example the children (aged four years) worked to program simple robotic toys (Pro-bots) around square roads. Pro-bots use a simple user interface described in Highfield (2010) to enter and execute programs of movement. The task outlined in this example was one of many (outlined in Highfield 2010). Here to move the Pro-bot around the square path the children were required to input four steps on each side, then a turn, repeating this to complete the square. As a class the children watched as their teacher measured the road using the Pro-bots as a unit of measure, as can be seen in Fig. 5. Following this the children worked in pairs to solve the problem and successfully move the toy around the path.

The children also used chalk to indicate step length, drawing symbols on the pathway. One child began by using chalk to mark many steps (Fig. 6). After discussing how many steps he needed and re-programming the toy the child revised his problem-solving strategy (Fig. 7).

The boy used a symbol system to plan his pathway with the robot. His initial use of tally marks was modified to use arrows that are adapted from (or resemble in some way) the arrows seen on the Pro-bot itself. This task presented an opportunity for the children to estimate, measure and program the Pro-bot to move around a square track using the pre-set steps on the toy. This presented an opportunity for the children to demonstrate more planning and problem-solving. By planning their actions the children engaged with geometric concepts, such as the attributes of a square, including four sides of equal length and corners at a 90° angle. Further, the children engaged with these concepts concurrently with dynamic concepts, such as the robot rotating 90°, and each side requiring four steps.

Fig. 6 The child's initial representation of many steps for the road task

Fig. 7 The child's second representation using arrows to indicate steps for the road task

3. Constructive Technologies At the other extreme of the continuum (Fig. 2) is constructive multimedia. As the name suggests, such software is based on contemporary adoptions of constructivist approaches of teaching and learning and provides learners with the opportunity to generate their own mathematical representations. These types of software are based on the assumption that technology can be used as "cognitive learning tools" which can be employed to facilitate learning and support the thinking processes of learners (Jonassen 1994, p. 62). Hence, the technology functions as an expressive tool. In the current classification scheme, the term 'constructive multimedia' refers to technologies that allow learners to create multimedia artefacts. Hence, the learner constructs the representations using multimedia tools.

This type of technology provides opportunities for students' intuitive understandings to be made explicit. The learner uses the available digital tools inherent in the software to construct mathematical representations. Hence, these tools engage learners in meaningful learning activities that support critical and reflective thinking about concepts. These tools assist in providing insights into students' conceptions and provide unique opportunities for mathematical modelling and expression (Noss and Hoyles 1996). The software, in this instance, amplifies the students' learning, making explicit their mental models and levels of conceptual understanding. Modifiable graphics enable students to easily create their own multimedia representations not possible with inert media (Clements 1999). Further, many of these tools allow representation and, as young learners can save and re-visit these tools, may also promote reflection on learning.

Constructive multimedia programs demand a significant cognitive investment on the learner's behalf, as the onus is on them to generate the representation. As a result there is a low level of cognitive offloading, as the technology assumes some of the cognitive load for the learner. Effectively using these tools to convey conceptual understandings requires more sophisticated cognitive skills and a significant cognitive investment on the learners' behalf than more instructive multimedia. It is possible that learners may expend too much mental effort manipulating and selecting the digital authoring tools and thus, may detract from their learning.

Exemplars of Constructive Technology Constructive Technology Exemplar—2Simple software. In Goodwin's (2009) and Highfield's (2007) study the participants also engaged with constructive technologies. One example of this (arising from Goodwin 2009) was 2Create a Story (2 Simple Software 2006) used to create a multimedia fraction story. When using this tool, the onus was on the learner to construct the representation, as there were no representational models provided, as there were with the instructive and manipulable technologies.

The constructive technologies provided two key affordances for young learners: (i) they could externalise their thinking; and (ii) they could compensate for their developing fine motor and literacy skills. Using 2Create a Story (2 Simple Software 2006), the Kindergarten students were able to create a digital artifact with their own representations, symbol notation, and verbally explain their drawing. The computer mouse, in conjunction with the on-screen drawing tools, enabled the young learners to easily create a digital artifact that was indicative of their understanding of fractions. They were able to experiment and manipulate representations (they were unable to do this with the instructive technology used but were easily able to do this with manipulable technology). This ensured that their conceptual understanding of fractions was not constrained by their fine motor and/or literacy development.

The open-ended design of the constructive technology allowed for students to depict 'counter examples' of fractions, as shown in Fig. 8. Counter examples are described as representations that challenge conceptual understanding (conflict), to show why some conjectures and representations are false (Liz et al. 2006). In this study, counter examples were considered to be students' intentional depiction of an incorrect representation of a fraction, with an accompanying icon or

Fig. 8 A screen capture of a student's depiction of a counter example, using "2Create a Story" (constructive multimedia)

comment to signal that the representation was incorrect. Counter examples were also considered to indicate understandings of advanced fraction concepts. Figure 8 is an example of a counter example. The student formed the notion that half of an object needed to be two equal-sized pieces and had applied this idea to partitioning a rocket ship. There was no other multimedia activity, used throughout the research study, where a rocket ship was used to depict a half. Hence, the constructive technology allowed the child to demonstrate this sophisticated understanding of fractions, in a way not possible with other types of technology.

Similar findings were seen in Highfield and Mulligan's (2007) research, where constructive technologies enable ease of representation, representation of sophisticated concepts and prolonged engagement. Here these open-ended tools facilitated increased engagement in mathematical thinking and opportunity for more advanced representation.

Discussion and Conclusions

Whilst there is growth in the availability of technological infrastructure and interactive multimedia for early mathematics learning, there is a dearth of research exploring their effectiveness. Existing literature has called for further research to examine the impact of new technologies on young students' mathematics learning (Clements and Sarama 2002, 2004; Highfield and Goodwin 2008). The studies reported in this chapter have supported and extended current research by revealing that interactive multimedia has a substantial impact on young students' development of basic mathematical concepts. In addition, these studies provide evidence that different multimedia offer unique affordances for learners, in terms of their unique design attributes.

The studies presented in this chapter also challenge the widespread belief that young students are incapable of dealing with complex mathematical concepts.

Rather, the findings support previous research that young students are capable of dealing with powerful mathematical ideas (Ginsburg et al. 1999; Perry and Dockett 2008). These studies highlight the representational opportunities that technologies provide. Further, they highlight the dynamic presentation of information and the dynamic manipulation of materials as providing access to advanced mathematical concepts.

The cumulative data from these studies highlight the potential benefits of interactive technologies in early mathematics learning. New representational opportunities, afforded by interactive multimedia and digital technologies allow young students to explore and manipulate mathematical ideas in ways not previously conceived with more traditional teaching approaches and concrete materials. In turn, young children are able to explore more complex and advanced concepts than those proposed by traditional curricula. Goodwin's (2009) comparative analysis outlined substantial benefits of *manipulable* and *constructive* interactive technologies in early fraction learning. Students' representations after using *constructive* and *manipulable* interactive technologies in Goodwin's (2009) work showed more advanced and sophisticated concept images of fractions when compared to a traditional curriculum. Further, the use of these interactive tools enabled students to depict multiple representations and reflect and revisit work (Goodwin 2009; Highfield and Mulligan 2007). Within each of these examples children's active cognitive engagement enabled them to explore sophisticated mathematical content. Here technologies enabled mathematics learning beyond what is frequently encountered in traditional curriculum. In addition, Highfield (2012) demonstrated the potential affordances associated with simple programmable toys for problem solving, spatial and geometric concepts. These robotic toys provide a further example of *manipulable* technologies as a non-screen based tool.

Whilst dynamic, on-screen representations provide unique opportunities for young learners in terms of developing mathematical concepts, further research needs to explore how the pedagogic design of interactive technologies impacts on their potential to support young children's learning. As Goodwin's (2009) study exemplified, the inclusion of superfluous details such as animations and extraneous sound effects, as are typically included in *instructive* multimedia, place demands on the students' cognitive load. Students' attentional resources are often diverted to processing the redundant information included in screen embellishments and not on the embedded mathematical content. This limitation was more evident with low-achieving students, than high-achieving students, as they have a tendency to focus on the superfluous inclusions, hampering their understanding of the mathematical content. Hence, a closer examination of the pedagogic design of multimedia needs to consider its impact on young students' cognitive load.

Examinations of technologies for early mathematics learning, when presented within this framework, highlight the need for a range of pedagogic designs. Further critical analysis of learning afforded by the differing technological designs is needed to inform teacher pedagogic decisions. This has particular implications for teaching practice, where teachers must consider the pedagogic aim of their lesson sequence, prior to selecting technological based resources to support these goals. For example *instructive* technologies may provide opportunity to develop fluency in mathematical computation (e.g. factors to ten). Using these technologies the child could be presented with different combinations of numbers and be asked to provide a correct answer, with the real-time feedback enabling children to practice skills. Alternately, *constructive* technologies may enable learners to represent multiple alternate pathways of learning such as documenting strategies for addition rather than practicing pre-set tasks. Here, the teacher's purposeful choice of technology would need to be carefully aligned with their pedagogic goal.

Goodwin and Highfield's (2012) work outlines the dominance of *instructive* design for young children in new technologies, such as iPad Apps. Here again, judicious and purposeful selection of tools for specific mathematics learning is needed. These findings question the assumption that technology and interactive multimedia are always beneficial for learning (Goodwin and Highfield 2012).

Significant implications for future research arise from these studies, with further work investigating each of these pedagogic designs needed to effectively examine their potential affordances for young mathematics learners. Given that this age group is laying essential foundations for future mathematics learning it is imperative that the research agenda focuses on optimal technology use the early years. Further, dissemination of this research to teachers is needed, with additional research examining teacher pedagogic decisions also needed.

The studies reported in this chapter have assumed that students' language (used in interviews) and drawn representations are evidence of their learning. However, future studies utilising new data collection technologies such as digital brain imaging would be advantageous in examining the cognitive processes of students using interactive technologies. In addition, given the significant growth in touch technologies, such as iPads, further research is required to confirm whether the findings outlined in these studies are replicated with these new devices.

Implications for Teaching and Learning

The technological landscape is changing rapidly and new devices, applications and software are constantly evolving. As such, teachers need ongoing access to professional learning. Initial teacher qualifications alone are not sufficient for this technological society and need to be complemented by further opportunities for learning. Professional learning sessions need to have a dual focus: (i) they need to develop teachers' familiarity with various technologies (technological knowledge) and (ii) they must also focus on how to embed these technologies in sound pedagogical frameworks (pedagogical knowledge).

A consistent finding from both the Goodwin (2009) and Highfield (2012) studies relates to how young students find it difficult to interpret and process extraneous information contained within multimedia representations. Therefore, teachers must implement explicit strategies to ensure that young students develop the ability to locate the salient aspects within multimedia representations and avoid focusing on non-essential aspects. Structured follow-up questions and/or activities may assist the students, particularly the low-achievers, focus their attention on the mathematical aspects contained within the representation.

Using a design study approach, the Goodwin (2009) and Highfield (2012) studies also revealed how the design of the lessons in the interventions was an effective format when using technologies with young children. Common teaching practice often focuses on isolated and stand-alone use of technology, with a brief introductory session focusing on the technical and procedural aspects of the technological tool, followed by individual, pair-work, or small-group use of the multimedia. There is an emphasis on task completion, with little opportunity to discuss the students' learning. However, in these studies, discussion sessions were an essential component of the lesson sequence as it enabled the students to share their discoveries and showcase their work and seek peer assistance for difficulties. Teachers should ensure that a plenary, sharing component always follows individual or group use of multimedia.

The findings of the current study have exemplified differences in the way high- and low-achieving students use and respond to different multimedia and interactive technologies. It is paramount that teachers consider the students' prior knowledge when using any technology to align pedagogical approaches with students' needs. Hence, the impact and affordances are different for students at the extremes of achievement. This is not to suggest that *instructive* multimedia should not be used with low-achieving students. Instead, it is imperative that teachers ensure that after using *instructive* and *constructive multimedia* that plenary sessions are conducted to focus students' attention on the mathematical aspects of the multimedia. Alternatively, teachers can assign tasks for learners to complete during or after using interactive multimedia, to ensure that students focus on the intended learning in the multimedia. This is sound pedagogic practice that would benefit both high- and low-achieving students.

Implications for Further Research

There is a dearth of research that explores how young children use and respond to various technologies. Given that there has been an exponential growth in this sector, in terms of the availability of these resources for young learners, there is a dire need for more research to be concentrated in this area. The studies presented in this chapter provide evidence to indicate that young children's early mathematical learning can be enhanced through the use of various technologies, but they have also suggested that the design of the technology can have an adverse effect on learners.

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