A computer-assisted Framework based on a cognitivist learning theory for teaching mathematics in the early primary years

Abstract

With the world moving rapidly into digital media and information, the ways in which learning activities in mathematics can be created and delivered are changing. However, to get the best results from the integration of ICTs in education, any application’s design and development needs to be based on pedagogically appropriate principles, in terms of both learners’ and teachers’ needs. The first part of this paper provides an overview of relevant literature by presenting four interrelated key themes. Secondly, a new framework for using ICTs in the lower primary mathematics classroom (ages 5-8), based on current pedagogical views of mathematics education and a cognitivist learning theory, is proposed. Finally, suggestions for the development of appropriate software and multimedia content, based on the framework, are offered.

INTRODUCTION

In the twenty-first century, the use of Information and Communication Technologies (ICTs) has become an important and essential part of the everyday life, work, and learning. During the past decade, the impact of ICTs in different fields such as medicine, tourism, travel, business, law, banking, engineering and architecture has been enormous (Oliver, 2002; Ongori & Mburu, 2010; Pramanik, 2011). Within education, ICTs play an increasingly important role, not least as a means of transforming pedagogy and supporting children’s learning. This role is becoming more and more important and there is little doubt that this importance will continue to grow and develop in the 21st century (Oliver, 2002, Pramanik, 2011). The development of new ICTs has resulted in significant changes in the ways that teachers teach and children learn in schools. The appropriate use of technology has proven to have broad pedagogical affordances and invaluable potential to change teaching and learning. Hence, there is no question about whether teachers should integrate technology in their existing practices; in fact, the main issue now is how teaching can be transformed by technology through the creation and implementation of novel, transformative learning opportunities (Angeli & Valanides, 2009).

In Australia, there have been education policy shifts to include ICTs in the schooling system. ICTs have begun to have a place in education and access to computer-based technology in schools and classrooms has increased. This became more important when the Melbourne Declaration on Educational Goals for Young Australians (MCEETYA, 2008) stated, “Young people need to be highly skilled in the use of ICT” (Ministerial Council on Education & Affairs, 2008). According to the Melbourne Declaration, schooling should support the development of skills in the use of digital media and increase students’ effectiveness in learning over the next decade.

In regards to the teaching of mathematics in Australia, all State, Territory and Commonwealth Education Ministers some time ago agreed on a national goal that states ‘every child leaving primary school should be numerate’ (Doggie, McRae, & Rowe, 2003). However, Australian students are performing less well as measured by TIMMS (Trends in International Mathematics and Science Study) than they used to. In the TIMSS 2003 results, Australian and US students achieved similar levels. However, in TIMSS 2007, the USA outperformed Australia in almost all the items reviewed (Thomson & Buckley, 2009). Solid mathematical skills are prerequisites for school achievement, success in the workplace and in personal life. In recent years, attention to the importance of teaching mathematics to young children has increased (Clements, Sarama, & DiBiase, 2004; Saracho & Spodek, 2009) and it has been recognised that children should be given the opportunity to access powerful mathematical ideas through high-quality child-centered activities in their homes, schools and communities (Kilpatrick, Sowrfald, & Findell, 2001).

With the world around children moving rapidly into digital media and information, the ways in which mathematical learning activities are created and delivered have changed (Figueira-Sampaio, dos Santos, & Carrojo, 2009; Rahman, Ghazali, & Irsam, 2003). However, not all of the technology-based packages are usable for teaching and learning purposes within schools as they are not always designed with appropriate pedagogical frameworks in mind (Laullard, 2009; Mumtaz, 2000; Pattan, Arnedillo Sanchez, & Tangney, 2006).

The first part of this paper provides an overview of the place of ICTs in the Australian education system, particularly in regard to mathematics teaching and learning. Relevant literature is reviewed through the discussion of four interrelated key themes: (a) the use of ICTs in the 21st century school; (b) teaching mathematics in the lower primary school; (c) pedagogies in mathematics, and; (d) current computer based maths applications and their pedagogical limitations. A number of issues are raised about the design and use of computer-based applications in Australian educational contexts. This paper then presents a proposed a new framework, based on current pedagogical views of mathematics education, coupled with a cognitivist framing, for effective use of ICTs in mathematics classroom (for lower primary school children). Finally, some suggestions for the development of appropriate software and multimedia content, based on the framework, are offered.

LITERATURE REVIEW

The use of ICT in 21st century school and school curriculum

ICTs play a fundamental role in daily life and to exclude or relegate it from the educational context would be thoughtless (Yelland et al., 2001). It has been raised as a concern among business leaders, educators, policymakers and parents that traditional practices are not necessarily delivering the skills that students need, and it is evident that traditional education environments do not always seem to be appropriate for preparing students to be productive in the workplaces of the 21st century (Yelland, et al., 2001). Various research findings indicate that ICTs need to be integrated into education (Kim & Hannafin, 2011; Kozma, 2001; Liu, 2010; Mumtaz, 2000; Schacter, 1999) so that children can learn in new and dynamic ways and be prepared for the challenges of life in the 21st century (Yelland, et al., 2001).

Many studies have focused on technology integration in education and have concluded that ICTs can have a positive effect on student learning.
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(Chang, Wu, & Sung, 2011; Kozma, 2001; Liu, 2010; Mumtaz, 2000; Schacter, 1999). Studies also indicate that, with the help of interactive technology, students are able to learn more deeply; receive feedback on their performance, test their ideas and revise their understandings (Chang, Wu, & Sung, 2011; Kozma, 2001; Mayer, 2003).

In the past three decades, the place of ICTs in school has been changing from “learning about ICT” through “learning with ICT” to “learning through ICT” (Markauskaitê, 2004). However, in many school settings, ICTs are still only used as tools for designing instruction material and delivery, not as learning devices or central components of teachers’ instructional programs (Liu, 2010; Yelland, et al., 2001). In the primary classroom, there are many opportunities for ICTs to enhance the teaching of curriculum areas such as English and Mathematics, but appropriate supporting conditions need to be in place (Lim, Oakley & Liu, 2013).

A curriculum includes aims and objectives, subject matter or content, methods or procedures to teach content, as well as an evaluation or assessment component (Scott, 2008). Kozma (1994) asserted that schools need to reform curriculum and pedagogy since traditional forms of schooling were not designed to address the use of ICTs. “We are fitting new technologies into old curricula which were developed prior to their existence” (Yelland, et al., 2001). Several years later, new curricula have been developed in Australia, but teachers clearly still need support in modifying their pedagogies in order to use ICTs effectively. In the USA, the National Council for the Teachers of Mathematics (NCTM) has been successful in creating an agenda for reform of mathematics teaching, which has included the use of ICTs in the curriculum (Yelland, et al., 2001). Furthermore, the National Technology Leadership Summit, composed of teacher educators associations, stated that “ubiquitous computing will be a widespread force in schools by the end of the decade or sooner” (Bull, Garofalo, & Harris, 2002). This prediction has so far been accurate and computers and other ICTs are widespread in most schools in developed countries, including Australia; however, there is limited evidence to show that they are being used effectively in mathematics teaching and learning in primary schools.

In Australia, like other developed countries, the integration of ICTs across the curriculum has become a priority (Phelps, Graham, & Watts, 2011). In 2008, the Department of Education, Employment and Workplace Relations announced a “Digital Education Revolution”, which is focused on ICTs in schools – leadership, infrastructure, learning resources and teacher capability (Department of Education, 2008; Phelps, et al., 2011). As a result of this technological revolution, the pedagogical integration of ICTs across the curriculum has been highlighted, even in early years of schooling. For example, in the Year 2 mathematics curriculum, children should learn to describe and draw two-dimensional shapes with and without digital technologies.

The Australian Curriculum, Assessment and Reporting Authority (ACARA) and The Australian National Standards for Teachers (AITSL, 2011) both include a strong focus on the use of ICTs across the curriculum. They encourage teachers and students to use ICTs in the classroom to make calculations, draw graphs and interpret data, create spreadsheets, and practise with dynamic geometry software and computer algebra software in ways that have previously not been possible (ACARA, 2011a). Thus, as noted above, the issue is no longer whether ICTs should be integrated in existing classroom practices, but how to use it to transform teaching and create new opportunities for learning.

By having the new Australian Curriculum, which introduces the use of ICTs as a ‘general capability’ across the curriculum, and the Australian government’s “Digital Education Revolution” policy, there is no doubt about the need for quality studies in this area. Many studies and computer-based applications that are currently used in Australia originate from the USA and in recent years more have been coming from the UK (Eng, 2005; Yelland, et al., 2001). Subsequently, educational packages are mainly based on the curricula of these countries and their teaching philosophies and methods. Thus, in many cases, sourcing computer-based technology and applications to facilitate learning in a pedagogically acceptable manner has become an area of challenge for Australian schools. Thereby, there is a great need for Australian-based quality applications to address and cover the needs of Australian teachers and students.

Teaching mathematics in the lower primary school

Mathematics has a central position in primary school curricula (Anthony & Walshaw, 2009) and mathematical understanding influences decision making and increases opportunities for young people in their current and future private, social and civil lives. Unfortunately, today, as in the past, many students struggle with mathematics in the classroom and in their daily lives (Anthony & Walshaw, 2009; Offer & Bos, 2009). Due to these issues, there is an increased concern around the teaching of mathematics to young children (Clements, et al., 2004; Saracho & Spodek, 2009).

In 2008, the Department of Education, Employment and Workplace Relations announced a ‘Digital Education Revolution’, which is focused on ICTs across the curriculum has become a priority (Phelps, Graham, & Watts, 2011). The Australian Association of Mathematics Teachers and Early Childhood Australia (AAMT/TECA, 2006) states that:

“The Australian Association of Mathematics Teachers and Early Childhood Australia believe that all children in their early childhood years are capable of accessing powerful mathematical ideas that are both relevant to their current lives and form a critical foundation for their future mathematical and other learning. Children should be given the opportunity to access these ideas through high quality child-centred activities in their homes, communities, prior-school settings and schools.”

Yet it should be stressed that there is a need to update mathematics education for young children, and the transformational power of ICTs in society is a major driver of this need (Saracho & Spodek, 2009). Learning through technology, especially multimedia learning, can give children access to powerful new ways to explore concepts at a depth that has not been possible through traditional ways of teaching. A multimedia approach is a powerful tool for the visualisation and representation of mathematical concepts and can facilitate the learner’s abstract thinking. Using multimedia and computer-based tools can also allow multiple representations to be linked dynamically; for instance, changing a formula that can instantly change a graph (Milovanovic, et al., 2011) or showing a numeral and having multiple representations of the relevant number available in pictures, sounds and even animation.

Australia, along with other countries such as New Zealand, England, United State and Canada, has undertaken initiatives designed to improve the teaching and learning of mathematics among young children and to promote young children’s mathematical thinking. In recent years, the mathematics education of young children has received increased attention among Australian researchers (Clarke, Cheeseman, & Clarke, 2006; Perry, Young-Loveridge, Dolcett, & Dog, 2011; Thomson, Rowe, Underwood, & Peck, 2005; Young-Loveridge, 2004). The Australian Association of Mathematics Teachers and Early Childhood Australia (AAMT/TECA, 2006) states that:

“...
Pedagogy in mathematics

‘Pedagogy’ refers to strategies of instruction, or a style of instruction used to promote development and learning (Epstein, 2007). Teachers can provide opportunities for students to learn and understand mathematics concepts in various ways. Storytelling, fluency building strategies and problem solving are well known pedagogical approaches in mathematics education for young children.

Using children’s literature (storytelling) to teach mathematics has proven to be a very effective method (Elia, van den Heuvel-Panhuizen, & Georgiou, 2010; Tucker, Boggan, & Harper, 2010) and can motivate learners to think, to imagine, and to learn (Zazkis & Liljedahl, 2009). Telling mathematics concepts through stories can create powerful and memorable images in a learner’s mind (Zazkis & Liljedahl, 2009) and help them link mathematics concepts to their existing knowledge and understandings about the world.

‘Fluency’ is the ability to express something effortlessly, clearly and with automaticity. Maths fluency can be described as the ability to compute maths facts (e.g. addition, subtraction, multiplication and division) and problems quickly and with confidence (Mercer & Miller, 1992; Tait-McCUTCHEON, Drake, & Sherley, 2011). According to ACARA, students are considered to be fluent when they can calculate answers efficiently and confidently, find various answers, recall definitions and (for older children) manipulate equations and terms to find answers (ACARA, 2011). The recall of basic facts is recognised as a vital goal of mathematics education in primary schools since the prompt recall of mathematics facts can ensure that students have the cognitive capacity to attend to the more complex activities of problem solving and higher-order processing (Tait-McCUTCHEON, et al., 2011).

‘Problem solving’ can be described as a process of working through the details of a problem to reach a solution and is recognised as a very important task in mathematics education (Lazaxidou & Retalis, 2010). Elshout identified problem solving as a cognitive function that requires the problem solver to recall and process the relevant information (Elshout, 1987). Although the construct of problem solving has no commonly accepted definition in mathematics education, it undoubtedly involves higher order thinking (HOT), which depends to a large extent on the fluency of lower level learning.

The project being reported here draws on a cognitivist approach to learning, which focuses on mental processes and how learners attend to, manipulate and remember information during learning. Cognitive education in the teaching and learning process encourages learners to think, to imagine, and also the opportunity to learn from their peers.

To add to the above issues, the provision of feedback to children has often been a weak link in educational software, offering little beside whether the child’s response is correct or incorrect (Gadanidis, 2004). Immediate and appropriate feedback to children has often been a key to computer-based education (Clements, 1987; Elia, van den Heuvel-Panhuizen, & Georgiou, 2010, 2011). However, current educational applications are rarely based on the requirements of education, in terms of both learners’ and teachers’ needs. Inappropriate use of multi-media in terms of educational content and an inadequate ability to provide an effective learning environment are other problems associated with educational software (Sim, MacFarlane, & Horton, 2005). Many current applications are largely driven by financial, logistical and technical agendas and not pedagogical considerations, and they mainly concentrate on the software itself and not the educational theory underpinning it (Patterson, 2006). Further to the above issues, there is all too often a disconnection between theory for designing educational applications and theory relating to the application of technology in classrooms (Offer & Bos, 2009), as well as a lack of alignment between technology, curriculum and pedagogy (Mumtaz, 2000; Yelland, et al., 2001).

Statement of the problem

It is clear from this literature review that there is potential for mathematical computer-assisted framework based on a cognitivist learning theory for teaching mathematics.
achievement to be improved in schools through the effective design and use of ICTs, especially computer based and multimedia educational applications. However, it is argued that not many educational applications fit well in Australian primary school settings to facilitate mathematics learning in a manner that is considered to be pedagogically appropriate by teachers. Hence, there is a need to design an educational framework, based on accepted pedagogical approaches before developing any educational software and multimedia content. The next section of this paper proposes a new framework based on a cognitivist learning theory for effective use of ICTs in mathematics classrooms for lower primary school children.

Theoretical Framework

The Bloom/Anderson taxonomy is a useful learning model and is widely used as a planning tool in educational settings (Krause, Bochner, & Duchesne, 2006), and has been applied in higher education domains such as engineering, structuring assessments and computer science for course design and evaluation (Thompson, Luxton-Reilly, Whalley, Hu, & Robbins, 2008). However, the approach has seldom been used for designing computer-based educational applications for schools. In the study being discussed here, the Bloom/Anderson taxonomy has been used to inform the design of a mathematics educational framework, which has in turn underpinned the design and development of a computer-based application to facilitate the teaching and learning of mathematics concepts to children in lower primary school classrooms.

Figure 1 illustrates the base of the Bloom/Anderson taxonomy, which consists of six major categories including of Remembering, Understanding, Applying, Analysing, Evaluating, and Creating (Anderson, et al., 2001). The first three categories of Remembering, Understanding and Applying require a good deal of involvement and scaffolding from teachers, and focus on knowledge, comprehension and application. The last three categories are more sophisticated and need higher orders of thinking by learners. These elements emphasise analysis, evaluation and creativity.

Figure 1: Categories in the cognitive domain of Bloom's Taxonomy (Anderson, et al., 2001) Source: http://www.educationworld.com/a_curr/mathchat/mathchat026.shtml

We propose a new framework for designing mathematics software, which captures all elements of the Bloom/Anderson taxonomy (Figure 2). As mentioned in the literature review, storytelling, skill building (fluency building) and problem solving are three effective approaches to mathematics education for young children, and these three approaches are at the core of the proposed framework. As is shown in figure 2, storytelling is the first level of the framework (lower section), where the whole class can be engaged. Here, there is substantial teacher involvement (scaffolding) to focus children’s attention on the story and the embedded mathematical concepts and build comprehension. The storytelling methods can assist learners with reference to the recall of facts, terms and concepts, and can encourage them to imagine and sequence story scenes (Krause, et al., 2006; Tucker, et al., 2010). This ties in with the “Understand” category of the Bloom/Anderson model. Therefore, storytelling covers both “Remembering” and “Understanding” in the Bloom/Anderson model.

The middle section of the framework focuses on the skill building of individual students through the use of knowledge and understandings already gained through the first level. Skill building (fluency building) can be described as a way of learning by developing a capacity to retrieve basic facts from memory quickly and effortlessly (with automaticity). This can be achieved through practising, repeating and accomplishing. For example, readily counting numbers in sequences and continuing patterns can be achieved through regular corrected practice. This aligns with the “Apply” category of the Bloom/Anderson model.

Problem solving is a “higher-order cognitive process” (Goldstein & Levin, 1987) that entails the ability to recognise, understand and analyse a problem. Then, all of the components need to be evaluated and incorporated to create a new form or representation. This can be related to the last three categories ("Analyse", "Evaluate" and "Create") of the Bloom/Anderson model, which require a higher order of thinking by learners (Anderson, et al., 2001). As it presented in Figure 2, this is the upper level of the proposed framework, where students can work individually or in pairs or small groups to analyse and find solutions to maths problem. Learners have the opportunity to move back and forth between these three levels of framework, if required.

![Figure 2: Proposed educational framework](image1.png)

The conceptual ties between the Bloom/Anderson model and the proposed framework provide a strong basis for designing a computer based mathematics educational application (Figure 3).

![Figure 3: The conceptual ties between the Bloom/Anderson taxonomy and the proposed framework](image2.png)

**Proposed computer based mathematics educational application**

Using children’s literature with a focus on reading, writing, and communicating mathematically is argued to be an effective way to motivate, engage and inspire children to explore mathematical concepts actively and enthusiastically.
There are many books that can be used effectively and creatively in the classroom for teaching in the field of mathematics. However, not every book will be appropriate for enhancing a mathematics lesson; there should be a natural relationship between the book chosen to enhance the lesson and the lesson itself (Price, 2009). Embedding mathematics concepts within a story and presenting it in a multimodal way by using pictures, audio, video and informal, familiar language can help children grasp the mathematical ideas and concepts more keenly (Ward, 2005), and the proposed mathematics application capitalises on this.

Based on a review of existing mathematics concept books and discussions with teachers and other mathematics educators, the researchers chose an engaging mathematics concept book, “One is a Snail, Ten is a Crab”, a counting by ‘feet’ book written by April Pulley Sayre, Jeff Sayre, and Randy Cecil (2003). This picture book is about counting animals with various numbers of feet, e.g., “5 is a dog [with 4 feet] and a snail [with 1 foot]”. With permission from the publisher, the researchers have used this book to design and develop an interactive multimedia application that contains mathematical concepts relevant to the early primary curriculum (Years 1-3).

The proposed computer based application is, as previously mentioned, based on the Bloom/Anderson taxonomy and the aim is to produce educational multimedia texts or stories that encourage the cognitive learning objectives in the Bloom/Anderson taxonomy. Since our target audience is lower primary students, a high level of computer skills cannot be assumed and, hence, the system needs to be simple, clean and easy to use to encourage mathematics learning without the technology ‘getting in the way’.

The interactive multimedia educational application, called My Maths Story, applies the cognitive learning objectives through the use of technology with a strong theoretical underpinning. Teachers and educators should be able to use this interactive application to introduce many mathematical concepts relevant to their classroom and curriculum. They will also be able to generate their own stories by choosing appropriate characters, settings and multimedia content. Students have opportunities to interact with the story and introduce variations (and even to pose their own problems) to permit engagement with the relevant concepts more thoroughly and deeply. The My Maths Story application should offer teachers many opportunities to share and discuss a range of mathematical concepts for various ability levels, within the motivational context of a storybook that links mathematical concepts to real world events and settings. Mathematical language is reinforced and extended and cross curricular links are made with literacy. Moreover, the application can be adapted to multiple grade levels and can be used to target different learning objectives throughout the school year.

Younger children can learn counting, place value, number sense, number relationships and basic addition, while older children can benefit from using this application to learn skip counting, counting by sets of 2s, 4s, 10’s, even and odd numbers, addition, subtraction and multiplication in different ways. The application also allows for problem solving when presenting certain numbers to represent different animals according to the amount of feet on each animal. The story can be generated over and over, each time using different mathematical concepts and expressions, and each time becoming more complex. For example, when teaching addition and subtraction concepts in lower primary, teachers can use My Maths Story application to generate stories to help teach addition and subtraction concepts involving one, two or three digit numbers. Teachers can create interactive stories by choosing scenes, characters (e.g. a snail, person, dog, insect, spider, crab) and appropriate multimedia such as sound and text. Also, teachers can emphasise the intended learning outcomes or objectives by creating a new story, explaining the scene, retelling, and asking ‘why’ and ‘how’ questions. This can help students to recall facts, terms and concepts by remembering, describing and explaining (the “Remember” and “Understand” categories of Bloom/Anderson model-lower level of the proposed framework).

Further, students can use this system to interact with the story for practising and repeating the targeted maths concept(s). Through interacting, manipulating, and creating various stories, students can build fluency skills by calculating answers, finding various answers and recalling factual knowledge and concepts readily (the “Apply” category of Bloom/Anderson model-middle section of the proposed framework). This system can also be used for more complex maths concepts, by generating a story and asking students to analyse, explain, understand and solve a problem individually or in pairs (the “Analyse”, “Evaluate” and “Create” categories of Bloom/Anderson model-middle section of the proposed framework- upper level of the proposed framework). Below are screen shots of the My Maths Story application, which is in the final stage of development and will be used for teaching primary school students for approximately one school term, in three primary schools in Western Australia. The details of the various components of the system and the evaluation of this application will be discussed in future publications.

Figure 4: The Interactive Multimedia Application

Conclusion

The integration of ICTs into the learning environment can provide valuable learning experiences when it is designed and utilised in a pedagogically appropriate manner; to get the best results from the integration of ICTs in education, any application’s design and development needs to be based on accepted pedagogical principles, in terms of both learners’ and teachers’ needs. This paper presents an educational framework for teaching mathematics that is based on Bloom/Anderson’s taxonomy and current pedagogical views of mathematics education. With this underpinning framework, it has been possible to design and develop an interactive multimedia application for teaching mathematics in lower primary school classrooms. This application is to be evaluated in schools then refined in response to the findings. It is envisaged that this new software, because of its theoretical and pedagogical underpinnings, will not have the same kinds of shortcomings as many of the existing mathematics software packages.
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Authors Note

Nasrin Moradmand

Nasrin is a researcher and PhD candidate in the School of Computer Science & Software Engineering, the University of Western Australia. She has a background in computer engineering and training and assessment. She worked in Information Technology environment for the past ten years and interested in advanced research for women and children, especially in relation to their education and health. The aim of Nasrin’s current research is to investigate how teachers and students can use appropriate computer-based educational applications in the classroom to enhance mathematical achievement.

Amrita Datta

Amrita did his MTech and PhD in computer science from Indian Institute of Technology, Madras. He has worked at the Max Planck Institute for Computer Science, University of Freiburg (both in Germany), University of New England and University of Western Australia (both in Australia). He has taught a broad range of subjects at both undergraduate and postgraduate levels. His research interests are in parallel and distributed computing, bioinformatics, computer-assisted education, mobile and wireless computing, social networks and data mining. He has supervised over 15 PhD and masters by research students, published over one hundred articles in reputed international journal and conference proceedings and served in the editorial boards and programme committees of several international journals and conferences.

Grace Oakley

Associate Professor Grace Oakley from the Graduate School of Education, the University of Western Australia, teaches in the Primary and Early Childhood programs and has special interests in digital literacies, mobile learning, literacy pedagogies and ICTs across the school curriculum.