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Integration of Information Technology in the Singapore School Mathematics Curriculum[1]

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Abstract: The paper traces the development of the integration of Information Technology (IT) into the mathematics curriculum in Singapore over the last ten years. It highlights the impact of the various Ministry of Education IT initiatives including the two Masterplan for IT in education on the teaching and learning of mathematics in Singapore schools. There is discussion of the emerging shift from the use of tutorial and drill-and-practice courseware in schools to reinforce the learning of mathematics to the use of open tools by teachers to create their own interactive mathematics resources to support the mathematics curriculum. Some challenges faced in the integration of IT into the mathematics curriculum are also highlighted.

Background

While the use of computing technology in Singapore education began in the early 1970s where the primary focuses were on the acquisition of computer literacy skills and the teaching of computer sciences (Wong, Lim, & Low, 1989), a system-wide application of information technology (IT) in education was given a significant impetus only with the launch of the first IT Masterplan for education (mp1) in April 1997. This strategic plan aimed to provide a blueprint for the use of IT in schools, and access to an IT-enriched learning environment for every student by 2002 (Teo, 1997; Cheah & Koh, 2001).

At the end of mp1, all Singapore schools had in place an IT infrastructure with a good range of learning resources provided. Teachers had acquired basic proficiency in IT integration with some teachers moving towards more innovative use of emerging technologies and new pedagogies. Schools have also achieved varying levels of IT use in administration and instruction. Research and development projects exploring innovative ways of using IT for teaching and learning had been conducted in collaboration with industry partners and/or Institutes of Higher Learning (IHLs). Singapore students have also done well in international competitions such as the ThinkQuest Internet Challenge and the International

[1] The paper is an updated version of the paper presented at the 9th Asian Technology Conference in Mathematics held in Singapore from 13 December to 17 December 2005.

Olympiad in Informatics. For ThinkQuest 2000, Singapore had the second largest number of entries, finalists and award winners (after the US). Internationally, Singapore has been recognised as a leader in the use of IT in education (see, for example, Kozma (2003)).

With the completion of mp1 in 2002, the second IT Masterplan for Education (mp2) was launched in July 2002. In moving forward, mp2 (from 2003 to 2008) would be consolidating and building upon the achievements of mp1. The underlying philosophy of mp1 remains relevant for mp2; that is, education should continually anticipate the future needs of society and work towards fulfilling these needs. The vision of mp2 is that IT will be pervasively and effectively used to enhance educational processes and structures to help realise an ability-driven education. The shift from mp1 to mp2 is towards seamless integration of IT into the curriculum to support a more student-centred learning environment, more autonomy for schools in terms of technology implementation, increased access to dynamic multimedia content, and the exploration of ubiquitous computing.

This paper will provide an overview of the integration of IT into the mathematics curriculum in Singapore over the last ten years from the perspective of the Singapore Ministry of Education. Much of the work carried out by colleagues at the National Institute of Education will not be discussed in this paper. First, we will briefly outline the context for the integration of IT into the mathematics curriculum in Singapore schools. Second, we will trace the development of IT use in mathematics education in Singapore schools. We will focus our discussion on the following two areas: integration of IT-based resources by mathematics teachers in their lessons and the professional development of mathematics teachers. Finally, we will share the challenges of preparing mathematics teachers to achieve effective and pervasive use of IT in the mathematics curriculum in Singapore schools.

Singapore Mathematics Curriculum

Mathematical problem solving is central to the Singapore mathematics curriculum at all levels from primary up to pre-university studies (See, for example, Lim (2002), CPDD (2005), SEAB (2006)). It involves both the understanding and the application of mathematical concepts, procedures and processes to a range of situations that include non-routine, open-ended and real-world problems. The development of mathematical problem solving also involves the affective aspects of mathematics learning that include appreciation, interest, confidence and perseverance as well as the metacognitive dimension of being aware of and the ability to control one's own thinking and learning in the problem solving process. Figure 1 below summarises the mathematics framework used in Singapore schools.

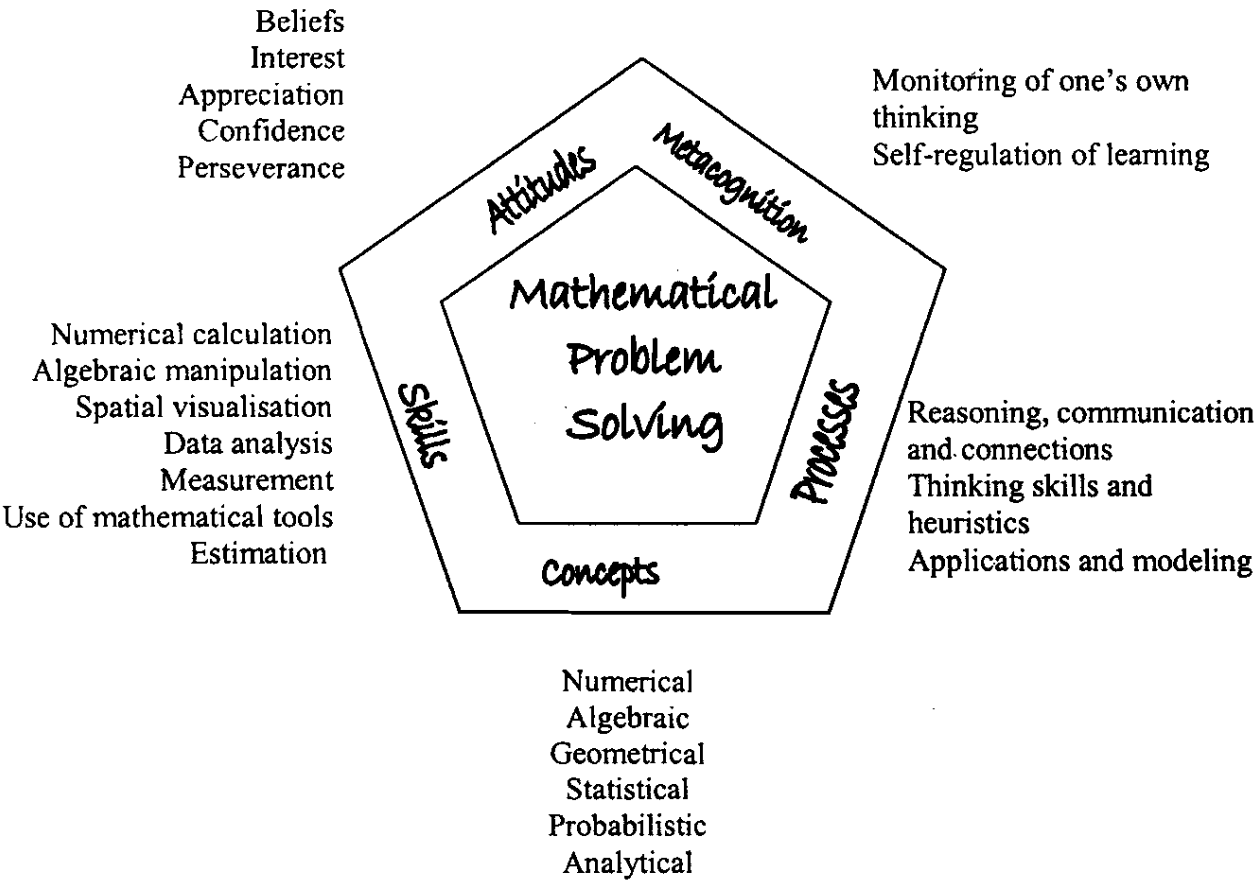

Figure 1: Mathematics Framework

Use of IT in Mathematics Education

The appropriate use of IT can increase the level of sophistication in students' understanding by supporting the development of mathematical concepts, procedures and processes through connecting new knowledge to students' prior knowledge and experiences in meaningful ways that are situated in appropriate social interactions involving peers and teachers with digital manipulatives (Hung, 2002; Alagic, 2003; Clements & Samara, 2005; Fuson, Kalchman, & Bransford, 2005). IT can assist in making mathematical knowledge come "alive" by making visible the metacognitive or thinking processes of both teachers and students. Table 1 offers a basic framework to look at the usefulness of IT in facilitating students' learning of mathematics in Singapore schools. The effective integration of IT into the mathematics curriculum involves achieving a balance of the various uses of IT as outlined in Table 1 based on the needs of learners situated within a social context.

Table 1
Framework for the Use of IT in Mathematics Education

Tool	**Function**	**Examples of Usage**
Productivity	To help teachers and students to manage and speed up administrative tasks associated with teaching and learning mathematics.	Teachers could use productivity software such as Microsoft Equation in Microsoft Word to prepare lesson notes and activity sheets. Teachers could use personal digital assistants such as Pocket PCs to manage administrative tasks such as attendance, analysis of marks, project monitoring, etc. Students could use Microsoft Word to create reports.
Informational	To facilitate students' access to information on mathematics.	Teachers could incorporate interesting biographical information on famous mathematicians from the web into their lessons to stimulate interest in the development of mathematical ideas. Students could visit websites containing everyday application of mathematics to gain better understanding of mathematical concepts and procedures.
Instructional/ Assessment	To assist teachers to automate aspects of teaching mathematics and assessing learning.	Teachers could assess students' understanding of simple mathematical concepts and procedures using drill-and-practice software. Teachers could use Classroom Performance System (http://www.einstruction.com/) to obtain immediate formative feedback on students' learning. Students could go through self-directed learning using tutorial software to learn some simple mathematical concepts and procedures.
Visualisation/ Simulation	To facilitate learners in recognising patterns/trends/	Students could use the spreadsheet software or interactive geometry software to get a better understanding

Tool	Function	Examples of Usage
	relationships and in visualising or simulating abstract mathematical phenomena.	of mathematical concepts by being able to explore what-if scenarios. Students could use the graphing freeware, Graph 3.1 to learn optimisation problems involving inequalities (Ang, 2004).
Connection	To allow teachers and students to engage one another on mathematics learning anytime, anywhere.	Teachers could use online discussion forum to discuss professional matters with one another or with experts in the different schools locally or overseas (Lehman, Warfield, Palm, & Wood, 2001; McDuffie & Slavit, 2003). Students could potentially interact with one another or with their teachers on learning some aspects of mathematics through a collaborative discussion forum such as Knowledge Forum (De Corte & Verschaffel, 1999).
Reconstruction	To provide students with an integrated learning environment that is equipped with a suite of IT-based tools for the reconstruction and experience of some subdomain of mathematics.	Students could apply mathematical concepts to solve authentic problems as in the Jasper Woodbury project (Vye, Goldman, Voss, Hmelo, & Williams, 1997) (http://peabody.vanderbilt.edu/projects/funded/jasper/ Jasperhome.html). Students could use the MathWorld environment to explore the mathematics of change and variation through, for example, examining relations among position, velocity and acceleration (Roschelle, Kaput, & Stroup, 2000) (http://www.simcalc.umassd.edu). Students could interact with microworlds to engage in the exploration of mathematical ideas (Noss, Healy, & Hoyles, 1997; Edwards, 1998).

Impact of IT Masterplan on the Mathematics Education

Integration of IT-Based Resources in Learning Mathematics

Before the implementation of the IT Masterplan, Singapore teachers, in practice, generally used teacher-centred instructional approaches where textbooks were the main teaching resources used to support the teaching of mathematics in the schools.. A typical mathematics lesson would be conducted in the following sequence. A teacher would begin the lesson by briefly presenting the mathematical concepts or procedures on the chalkboard/whiteboard to be followed by working out one or two problem examples as illustration for the students in the class. The teacher would then assign some time in class for seatwork for the students to work out similar problems. Finally, additional exercises would be given as homework to reinforce the learning achieved.

However, in the early 1990s, the Ministry of Education (MOE) explored the use of computer-assisted instruction (CAI) in mathematics education through the development of the Microsoft-DOS based *Primary Maths Series* by the former Curriculum Development Institute of Singapore. This series of CAI courseware provided drill-and-practice on a range of mathematics topics in the primary 3 to 6 curriculum. The courseware gave immediate feedback to the learners as well as provided the appropriate scaffolding to guide learners in their problem solving tasks. Although the CAI courseware was not integral to the curriculum then, a significant number of primary school teachers made the first attempt in using IT in a significant way in their teaching.

With the implementation of mp1, schools were equipped with the necessary IT infrastructure and teachers were provided with basic training in the use of IT applications and integration of IT into the curriculum. The implementation was done in 3 phases over a period of 5 years (from 1997 to 2002). During mp1, mathematics teachers began to use software such as Microsoft Word and Microsoft PowerPoint to prepare lessons and lesson materials such as activity sheets in a routine manner. Mathematics teachers also started to incorporate web-based information into their lessons to make them interesting. Students were encouraged to access web sites for more information and ideas for the learning of mathematics.
With the earlier success of the *Primary Maths Series*, MOE invested further resources to develop more multimedia drill-and-practice and tutorial courseware for the teaching of mathematics. This included the *Active Primary Maths Series*[2] for primary schools and the *Dynamic Mathematics Series*[2] for lower secondary schools. The latter series of courseware were developed in partnership with the industry. Some of the courseware had won international awards, for example, "Rainbow

[2] See http://www1.moe.edu.sg/edsoftware/ for more information.

Rock" was awarded the Bronze World Medal for the Mathematics and Computer Science category at the 1999 New York Festivals Interactive Multimedia Competition in Education.

As part of the IT Masterplan implementation, MOE did a mass acquisition of good mathematics courseware (both developed by MOE and by other publishers) and simple open tools and disseminated to all primary and secondary schools to promote the use of IT in the teaching and learning of the mathematics. The availability of courseware, together with the IT infrastructure put in place that included the provision of IT equipment to schools and the basic IT training given to all school teachers, prompted a more widespread use of IT in the mathematics curriculum by teachers in schools. The teachers would incorporate the various courseware provided such as the *Active Primary Maths Series* or the *Dynamic Mathematics Series* into their lessons for their students to work on the tutorial or drill-and-practice exercises provided during curriculum time. With the availability of access to Internet in classrooms, some mathematics teachers would also use the web-based resources such as Java applets and Flash animations to illustrate mathematics concepts/principles; for example, Pythagoras theorem.

The introduction of dynamic modelling tools that can help students to visualise abstract mathematical properties sparked off interests in Singapore teachers to use open tools to allow pupils to explore and discover mathematical concepts. At secondary level, teachers were using open tools such as *Graphmatica* to get students to explore the properties of quadratic graphs that included gradient and turning points. They also used *The Geometer's Sketchpad* (GSP) that provided screen-based notations to explore geometric constructions for the simulation of transformations like reflections and rotations directly on the computer.

At the primary level, spreadsheets had been introduced innovatively to amplify mental functioning even though its original intent was to support business decision and accounting operations. Primary school mathematics teachers had used the graphing capability of the spreadsheet software to generate charts like pictograms, bar graphs and pie charts to help their students in data representation, interpretation, reflection and calculation of quantitative information. At the secondary level, teachers used spreadsheets to design appropriate templates that allowed their students to exercise skills such as analytical thinking and abstract reasoning in decision making. For instance, students used spreadsheet templates created by their teachers to calculate bank loans and compound interests with variance in the interest rates while they study the payback trends.

As the implementation of the IT Masterplan progressed, more mathematics teachers became comfortable with the use of IT in their lessons. They began relying less on commercially available courseware to using more of their own teacher-created interactive resources to integrate IT seamlessly into the mathematics curriculum. The more enthusiastic early adopters, for example, explored the use of open tools such as *The Geometer's Sketchpad* (GSP), Microsoft Excel and Macromedia Flash to create their own interactive mathematics resources for their teaching. They used tools such as Hot Potatoes and Math Explorer to create online quizzes to assess the learning of mathematics. They also used the Classroom Performance System to get immediate feedback on all students' learning on a whole-class basis.

> *Thus, with the continuing support from MOE and the rapid development of user-friendly web-based technology, more teachers are moving from mere incorporation of commercially available learning resources to the creation of dynamic and interactive digital content to support their students' learning. Increasingly, teachers are moving from CD-ROM based digital content to web-based interactive learning objects. Teachers are gradually moving away from a teacher-centred approach to more learner-centred approaches that entailed higher order thinking in the teaching of mathematics.*

To date, teachers had designed numerous learner-centred lesson packages that utilized IT to teach mathematical concepts to their pupils including developing microLESSONS packages (Divaharan & Wong, 2003). MicroLESSONS was an approach for designing student-centred IT-based lessons pioneered by Learning Sciences Academic Group lecturers from the National Institute of Education. Teachers also made use of digital manipulatives that were created using open tools such as *The Geometer's Sketchpad* (GSP) to allow pupils to manipulate and deduce abstract concepts such as understanding fractions at the primary level. By changing the values of the numerator and denominator, pupils observe how they affected the value of a fraction through simulated visualization.

More recently, there is also a move towards crafting learning tasks that are authentic and engaging in an integrated manner (Hung, Cheah, Hu, & Cheung, 2004). There is stronger focus on the facilitation of actual learning of concepts and processes such as problem solving heuristics and higher order thinking skills. For example, one primary 6 class participated in an exploratory study where they learned from a planning-a-class-outing problem scenario. This study was developed based on anchored-instruction principles and which used Knowledge Forum, a computer-supported collaborative-learning software package (Etheris & Tan, 2004). Also, 600 Primary 5 students from 15 primary schools participated in a project called "Project eN3prise Wireless" where they were armed with PocketPCs to solve authentic problems on the value of money. They were assigned tasks to work out the most economical handphone plan to purchase based on mobile-phone subscription plans advertised by various mobile-phone vendors and to determine a saving plan for their future tertiary education based on financial planning parameters.

Professional Development of Mathematics Teachers

The training of mathematics teachers in the effective integration of IT into mathematics teaching and learning is an important component of both IT Masterplans. The emphasis of the training of mathematics teachers in Singapore is on the pedagogy of using IT in teaching and learning rather than on the acquisition of IT skills. The philosophy behind the training is that IT should be an enabler that supports rather than drives mathematics pedagogy.

The implementation of mp1 for Singapore schools was done in 3 phases over a period of 5 years. The National Institute of Education, being the sole teacher training institute in Singapore, is responsible for ensuring that all its graduates have the necessary basic ICT skills as well as the knowledge and skills for effective integration of IT into teaching and learning of mathematics. The Educational Technology Division at the Ministry (ETD/MOE) is responsible for providing basic training to all teachers in schools on the design of IT-based lessons that can effectively incorporate thinking skills, co-operative learning and classroom management strategies.

At the completion of mp1, mathematics teachers have achieved different levels of proficiency in the use of IT for teaching and learning as the training was conducted in phases. Different teachers in different schools also have different needs because of the different learning profiles of their students. Their proficiency in using IT tools range from use of IT as a presentation tool to adaptation of resources to teach mathematical concepts. Nonetheless, professional development programmes for teachers began with a one-size-fits-all approach where all teachers, regardless of their subject areas, were to attend a series of core school-based training workshops with aims to equip them with basic IT skills. This progressed to subject-based training which allowed mathematics teachers to gather and share effective pedagogical approaches in using IT for the teaching of the subject. Handholding sessions, mass lectures as well as various elective workshops have also been conducted. With the implementation of mp2, the professional development of Singapore teachers has gradually moved from a one-size-fits-all approach to one where schools can request for customized training workshops based on the needs of their school programmes.

Besides conducting training workshops, ETD/MOE also organized various seminars such as *EdTech99* and *iTopia 2002* to showcase schools' efforts to promote learning through the effective and innovative use of IT. Competitions for teachers such as *HP INIT Award* and *Microsoft-MOE Professional Development Award* were also initiated to encourage innovative use of IT in teaching.

Recent Developments

In going forward, MOE will intentionally include IT in the mathematics curriculum. For example, in the recent revision of the mathematics syllabus, the use of graphic calculators is included at the pre-university level mathematics. Through the use of graphic calculators, both in classroom practice and in examinations, teachers will be facilitating the development of students' learning in terms of data analysis and mathematical modelling, which will be important for nurturing the development of their mathematical knowledge skills[3]. At present, MOE is exploring the possibility of introducing calculators into the primary mathematics syllabus to enhance the teaching and learning process such as allowing pupils to handle calculations in real problems that involve numbers beyond their computational skills. This will also allow teachers to better balance the emphasis on computational skills with conceptual understanding and problem solving skills.

In addition, MOE will be collaborating with schools and the National Institute of Education to develop more IT-based pedagogies for the teaching of mathematics. The IT-based resources developed will be included in the teaching and learning guides and the lesson activities that would accompany the mathematics syllabus. In the next few years, there will be greater emphasis on the use of IT-based resources to support the learning of algebra and geometry at the secondary level. In the learning of algebra, IT-based resources will be developed to assist students to make the transition from problem solving using pictorial or model representation at primary level to using symbolic algebra at secondary level. Through the use of these IT-based resource developed, the students will also develop the ability to decide which of the methods – pictorial or symbolic representation would be most appropriate to use in problem solving. The use of interactive geometry software such as *The Geometer's Sketchpad* (GSP) will make it possible for students to experiment, explore and discover geometrical properties easily.

MOE will continue to study the potential of emerging technologies in the learning of mathematics to inform both practice and policy. Currently, R&D projects will include the development of possible models of IT-enhanced mathematics learning

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[3]Mathematical knowledge skills include gathering, synthesizing and analyzing information, devising practical solutions to problems, etc.

that embed formative assessment in instruction, the use of intelligent tutoring systems in primary mathematics instruction and the exploration of tablet PCs to support mathematics instruction. There are also schemes to support schools to study models of IT use in education that could potentially be replicated in other schools.

In order to ensure that there would be a minimum level of effective IT use in mathematics learning, MOE will be developing baseline standards for IT learning experiences of students, IT integration practices of teachers and planning practices of Heads of Department. Teachers will have access to exemplars of IT use in the mathematics curriculum that will model the effective use of IT in the teaching and learning of the subject.

Challenges Ahead

At the end of mp1, we have equipped all schools with the necessary basic IT infrastructure to conduct IT-based mathematics lessons. All teachers had achieved at least basic level of proficiency in the effective integration of IT into the mathematics curriculum. Teachers were provided with adequate provision of digital resources to support their teaching. In moving forward mp2 to achieve the vision of pervasive and effective use of IT in the curriculum, we need to move from providing teachers with a largely static content in print form to a repository of dynamic and interactive digital content. Teachers need to play a greater role in producing the latter content in order to allow for customising to the needs of the different learners in their classroom. We need also to shift from the predominantly teacher-centred pedagogies to more learner-centred pedagogies. Teachers need to make more use of IT as a connection and reconstruction tools (see Table 1) in order to expand the learning opportunities of their students. Hence, teachers play a crucial role in the successful implementation of mp2 to bring about the use of IT to new possibilities to engage students in the learning of mathematics. We face at least three challenges in addressing the issue of the professional development of mathematics teachers so that they will be able to be innovative in exploiting the use of IT to bring about engaged learning of mathematics for their students.

The first challenge is moving from a one-size-fits-all approach in professional development (PD) delivered on a just-in-case basis to one that is able to be customised to the needs of mathematics teachers based on the needs of their individual school programmes delivered on a just-in-time basis. Given that we have limited resources, it would be difficult for ETD/MOE to support every school such that we can develop PD programmes that are individually tailored to the needs of the teachers in a particular school. As a start, a key strategy that ETD/MOE is adopting is to attach an Educational Technology Officer (ETO) to each cluster[4]. The cluster ETO will engage the Heads of Department in each school to determine the PD needs based on their respective school programmes for the year. The information gathered by the cluster ETOs will be aggregated to formulate PD programmes that best meet the requirements of the individual schools with similar needs. Specialists in the subject areas from ETD/MOE, experts from the institutes of higher learning, and appropriate educational software vendors from industry or early adopters from the schools will be engaged to deliver the PD programmes to key teachers in the schools grouped according to their similar needs. These teachers, when trained, in turn will cascade the training to the other teachers in the school after further customisation of that training to meet the actual needs of the school.

The second challenge is to bring about a change in teacher's pedagogical beliefs and approaches in the use of IT that supports engaged learning in mathematics. There is increasing evidence that the beliefs of teachers strongly influence their pedagogical practices in the classroom (Handal, 2003; Kynigos & Argyris, 2004). If the beliefs of the teachers are not aligned to the desired outcomes of mp2, that is, a more learner-centred environment for mathematics learning, it is likely that there would be very little change in instructional practices of the mathematics teachers in the desired direction of learner-centred pedagogies. One approach that we are currently taking is to share success stories of best practices in the use of IT in mathematics learning through our PD programmes and via our edu.MALL web site (http://www.moe.gov.sg/edumall/index.htm), a web portal for access to resources on the use of IT in education. However, the factors that affect a change in teachers' beliefs are complex. There will be a need for research to be done to understand the factors impacting on teachers' beliefs with regard to the use of IT in education. A study of teachers' beliefs on the use of IT in education would be an area of research to be pursued by ETD/MOE in collaboration with the National Institute of Education.

The third challenge in professional development of teachers is the fostering and sustaining of Communities of Practice (CoPs) for mathematics teachers to engage one another in professional development activities and the creation of digital resources that better meet the needs of their students. CoPs have been suggested as a possible effective approach in which to influence and sustain technology integration into educational practices (Seels, Campbell, & Talsma, 2003). The interaction among colleagues, and the sharing of experiences and mutual support that teachers can receive from their involvement in CoPs, can help encourage and promote the

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[4]The Singapore school system comprises 4 zones of schools. Each zone consists of 7 clusters of schools. Each cluster is made up of 12 to 13 schools (from primary to JC level).

effective adoption of IT into the mathematics curriculum. With the progression into the second phase of the masterplan for IT integration in education, a CoP for mathematics teachers has been set up via an online platform. The aim of this CoP is to support our mathematics teachers in their use of IT for mathematics for teaching and learning. The platform allows for sharing of learning resources, innovative instructional approaches, and teaching experiences. It also serves as a helpline for enquires on related issues. In this way, there will be more sharing and exploration of innovative ideas that taps on technology for the instruction of mathematics in our schools, and more teachers can be influenced to adopt the appropriate use of IT in mathematics teaching. However, the conditions for sustaining CoPs are still not fully understood.

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