Enactment of School Mathematics Curriculum in Singapore – whither research!

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Abstract

The official curriculum for mathematics in Singapore schools is based on a framework that has mathematical problem solving as its primary goal. It is detailed and one may say that the gap between the designated curriculum and teacher intended curriculum is often very narrow. This is so as the main source of instructional materials is textbooks which are very closely aligned with the official national curriculum. There is a dearth of research on the enactment of the curriculum in Singapore schools, with the few research studies done so far appearing to cover only a narrow focus. The author's view is that, even though only a few such studies have been published, schools have always been engaged in small-scale investigations, the findings of which are necessary to guide decisions on matters related to choice of textbooks and pedagogies for improved student learning. Considering all the published research and the investigative work undertaken by educators in Singapore, it may be said that the conceptual model proposed by Remillard and Heck is rigorous. In addition, the issues in this particular issue of *ZDM* offer educators, both classroom teachers and others, very good perspectives for research on the enactment of the school mathematics curriculum.

Mathematics curriculum, official curriculum, textbook, research, enactment, Singapore

1.0 Introduction

The focus of this paper is on the enactment of the mathematics curriculum in Singapore schools. It draws on the official curriculum, instructional materials, a few research studies related to mathematics curriculum in Singapore schools and the tacit knowledge of the author to address the following issues:

i) To what extent are the conceptual model proposed by Remillard and Heck (2014) and other issues raised in this issue of *ZDM* applicable to the kinds of research done in Singapore?

ii) How prescriptive is the national curriculum? What information is available about how the curriculum is enacted? Is the curriculum enactment discussed or even a research issue?

In addition, based on the papers in this issue of *ZDM*, this commentary makes some suggestions for further research, both within and across countries, related to the enactment of school mathematics curricula.

In Singapore since 1990, for mathematics the classroom curriculum, also known as the enacted curriculum, is shaped by the school mathematics programmatic curriculum that places emphasis on mathematical problem solving (Kaur, 2014). In the context of this paper, classroom curriculum refers to what is taught and learned in classrooms, represented by a cluster of events jointly developed by a teacher and a group of students within a specific classroom (Doyle, 1992a, b). It involves the translation of the intended curriculum into the implemented curriculum (Robitaille and Garden, 1989), where the intended curriculum refers to the curriculum plans set out in syllabus documents issued by the Ministry of Education in Singapore while the implemented curriculum is what teachers actually realise in their lessons.

2.0 Enactment of mathematics curriculum in Singapore

Deng, et al. (2013) construed curriculum in terms of three domains: the policy curriculum, the programmatic curriculum and the classroom curriculum. They state that the policy curriculum "consists of educational policies and discourses at the intersection between schooling, culture, and society, embodying a conception or paradigm of what schooling should be with respect to the society and culture" (p. 6). It shapes the classroom curriculum, which is what is taught and learned in the classroom, via the programmatic curriculum. The programmatic curriculum "translates the ideals and expectations embodied in the policy curriculum" (p. 7) and "constitutes an organizational and operational structure within which classroom practice takes place" (p. 7).

In this issue of *ZDM*, the conceptualisation of the framework for describing and situating research on the enacted curriculum by Remillard and Heck (2014) illuminates two of the three domains of curriculum proposed by Deng, et al. (2013). These are the programmatic curriculum and the classroom curriculum. In Singapore, we have a centralised education system; the one other domain of curriculum, which is the policy curriculum, mainly outlines key thrusts of schooling and provides directions for reforming the school curriculum. It does not directly influence the programmatic and classroom curricula. So, for the study of the enacted curriculum in Singapore the framework proposed by Remillard and Heck, that hypothesises links between the official curriculum and the enacted curriculum and aspects of it, may be used for the purpose of documenting and exploring the links in and between the programmatic and classroom curriculum.

The official or programmatic curriculum for school mathematics in Singapore is very comprehensive. It comprises the background, goals and aims, the syllabus design – spiral and connected, the framework that underpins the teaching and learning of mathematics in the classrooms and the role of learning experiences, the principles of teaching, and phases of learning and assessment in the classroom. Figure 1 (Ministry of Education, 2012a, b) shows the coherent framework which connects the "product" conception of mathematics and the "process" aspect of it and links both of them to the five factors that facilitate the development of mathematical problem solving (Wong and Lee, 2010). It also represents an organising framework that "presents a balanced, integrated vision that connects and describes the skills, concepts, processes, attitudes and metacognition" (Leinwand and Ginsburg, 2007, p. 32). The intent of the framework, as articulated in the official curriculum (Ministry of Education, 2012a, b), is to help teachers focus on the five factors when enacting the curriculum so that they provide a more engaging, student-centred, and technology-enabled environment for learners and promote greater diversity and creativity in learning.

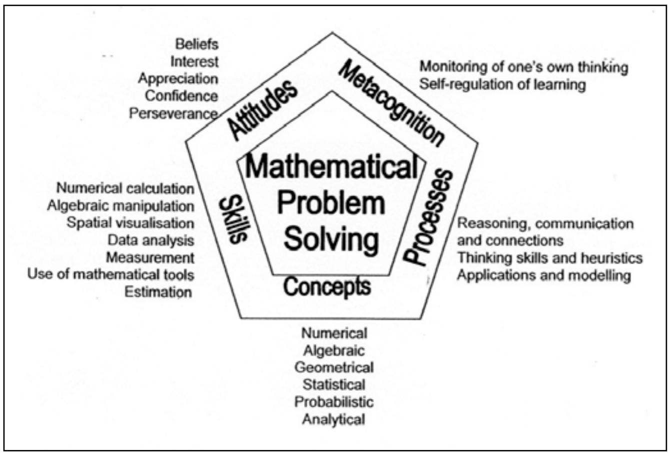

Fig. 1 Singapore School Mathematics Framework

The official curriculum also includes very detailed descriptions of what to teach at every grade level. Emphasis is placed on the learning experiences that teachers must facilitate for students' learning. Table 1 shows an excerpt from the primary school syllabus (Ministry of Education, 2012a, p. 37) and Table 2 shows an excerpt from the secondary school syllabus (Ministry of Education, 2012b, pp. 57–58). From both tables, it is apparent that statements expressed in the form "students should have opportunities to …" focus teachers on the student-centric aspect of learning mathematics.

The official curriculum also specifies the upper bound of the content that would be assessed at national examinations specifically at the end of primary schooling, that is, year 6, and secondary schooling, that is, years 10 and 11, depending on the courses of study the students pursue. At the school level, teachers also usually adhere to the scope of the content at the various year levels. The exceptions may be in the case of school-based decisions where some reorganisation of the official curriculum may have been undertaken for the purpose of integration across year levels. It is apparent from paper and pencil tests mainly used in the national examinations that often all the desired outcomes stipulated in the official curriculum are not testable and so one consequence of this is, as Ruthven (1994) notes, "what you test is what you get" (p. 433). When performance on only timed paper and pencil tests is all that matters, an undesirable consequence is that the implemented curriculum becomes a subset of the official curriculum.

Table 1
An excerpt from the primary mathematics syllabus

Primary Two (Grade 2)	
Sub-Strand: Whole Numbers	
Content	Learning Experience
1. Numbers up to 1000	Students should have opportunities to:
1.1 counting in	a) give examples of numbers in everyday situations,

tens/hundreds 1.2 number notation, representations and place values (hundreds, tens, ones) 1.3 reading and writing numbers in numerals and in words 1.4 comparing and ordering numbers 1.5 patterns in number sequences 1.6 odd and even numbers	and talk about how and why the numbers are used. b) work in groups using concrete objects/the base-ten set/play money to - count in tens/hundreds to establish 10 tens make 1 hundred and 10 hundreds make 1 thousand. - represent and compare numbers. c) make sense of the size of 100 and use it to estimate the number of objects in the size of hundreds. d) use the base-ten set/play money to represent a number that is 1, 10 or 100 more than/less than a 3-digit number. e) use place-value cards to illustrate and explain place values, e.g. the digit 3 stands for 300, 30 or 3 depending on where it appears in a number. f) use place-value cards to compare numbers digit by digit from left to right, and use language such as "greater than", "greatest", "smaller than", "smallest" and "the same as" to describe the comparison. g) describe a given number pattern before continuing the pattern or finding the missing number(s).

Table 2

An excerpt from the secondary mathematics syllabus

Secondary Three/Four (O-Level Mathematics) (Grades 9-10)	
Strand: Geometry and Measurement	
Content	Learning Experience
G2 Congruency and similarity	Students should have opportunities to:
2.7 determining whether two triangles are - congruent - similar 2.8 ratio of areas of similar plane figures 2.9 ratio of volumes of similar solids	a) construct triangles with given conditions, e.g. "3 sides", "3 angles", "2 sides, 1 angle", and "2 angles, 1 side", and examine what conditions are necessary for congruency / similarity.
G3 Properties of Circles	Students should have opportunities to:
3.1 symmetry properties of circles - equal chords are equidistant from the centre - the perpendicular bisector of a chord passes through the centre - tangents from an external point are equal in length - the line joining an external point to the centre of the circle bisects the angle between the tangents 3.2 angle properties of circles - angle in a semicircle is a right angle - angle between tangent and radius of a circle is a right angle	a) use paper folding to visualise symmetric properties of circles, e.g. "the perpendicular bisector of a chord passes through the centre". b) Use GSP or other dynamic geometry software to explore the properties of circles, and use geometrical terms correctly for effective communication.

- angle at the centre is twice the angle at the circumference - angles in the same segment are equal - angles in opposite segments are supplementary	
G4 Pythagoras' theorem and trigonometry	
4.4 extending sine and cosine to obtuse angles 4.5 use of the formula (½)(*ab*)(sin *C*) for the area of a triangle 4.6 use of sine rule and cosine rule for any triangle 4.7 problems in two or three dimensions including those involving angles of elevation and depression and bearings	a) visualise the height, north direction, right-angled triangle, etc. from 2D drawings of 3D situations. b) use the sine and cosine rules to articulate the relationships between the sides and angles of a triangle, e.g. the lengths of the sides are proportional to sine of the corresponding angles, Pythagoras theorem is a special case of the cosine rule, etc.

In Singapore, the main instructional materials for use by teachers are textbooks. The textbooks are produced commercially and compete for official adoption by the Ministry of Education. They adhere very closely to the official curriculum issued by the Ministry as this is a necessary condition for adoption. The publishers of the textbooks are closely guided by the curriculum specialists at the Curriculum Planning and Development Division of the Ministry of Education during the conceptualisation and writing phases of the books. The purpose of this is to ensure that the quality of the books meets the standards set by the Ministry of Education.

Kaur et al. (2006), in their study of grade eight mathematics teachers, who were recognised for their teaching competency in their respective schools, found that textbooks amplify an explicit link between the official curriculum and the enacted curriculum as they form a critical component of the teacher's intended curriculum. The teachers in the study stated that, as there was a tight alignment between the official curriculum and the content of the textbooks, they used mathematical tasks from the books for both learning and practice in their lessons. Also, Zhu and Fan (2002) in their study on the use of textbooks by mathematics teachers at grades seven and eight in Singapore found that textbooks were the main print resource for worked examples and exercises for mathematics teachers. Teachers often supplemented their collection of worked examples from other sources such as reference texts and/or e-resources available on the internet or in the form of CD-ROMs, but they almost always used the exercises in the textbooks for homework assignments. They also found that the academic status of the school, the teaching experience of the teacher and the gender of the teacher did not affect the ways in which teachers used the textbook.

How do Singapore textbooks for the primary grades compare with those in the United States? A study conducted by the American Institutes for Research (AIR) (Ginsburg et al. 2005, p. xii) found that mathematics textbooks used in Singapore schools build deep understanding of mathematical concepts through multi-step problems and concrete illustrations that demonstrate how abstract mathematical concepts are used to solve problems from different perspectives; while traditional US textbooks rarely get beyond definitions and formulas, developing only students' mechanical ability to apply mathematical concepts.

In short, it may be said that the official mathematics curriculum for schools in Singapore is very detailed. It drives the classroom curriculum as the main instructional material used by teachers is the textbook, which is tightly coupled with the official curriculum. The official curriculum also makes explicit the scope of the content for mathematics that would be tested at national examinations. In the next section we examine some studies that have been carried out in Singapore related to the enactment of the curriculum.

3.0 Some research studies on the enactment of the mathematics curriculum in Singapore schools

A few research studies related to the enactment of the mathematics curriculum in Singapore schools have been carried out to date. Most of these are related to the primary goal of the school mathematics curriculum, that is, mathematical problem solving. One main study, led by Toh (Toh et al. 2011a, 2011b), adopted an innovative approach to enact a problem-solving curriculum in secondary schools. Toh and colleagues used a "practical sheet with four explicit steps" to engage students in problem solving. The worksheet consists of four pages corresponding to each of Polya's stages of problem solving. In their study they show that irrespective of the content to be taught or the perceived ability of students, teachers may enact a problem-solving curriculum in their mathematics lessons. However, teachers need to develop their pedagogical knowledge and skills in order to enact the curriculum in the desired manner (Leong et al. 2011a, 2011b). Ho and Hedberg (2005) and Ho (2009) studied the enactment of mathematical problem solving in grade 5 classrooms in Singapore schools. They found that teachers adopted varying approaches to enact problem solving in their sequences of lessons. Their approaches were similar in some ways and yet different in other ways. Some taught for problem solving while others taught via problem solving. Most importantly, all of them engaged pupils with problem-solving heuristics in their lessons.

Fan and Zhu (2000) examined how two widely used mathematics textbooks in Singapore schools at the lower secondary, that is, grades 7 and 8, levels represented problem solving. They found that the two textbooks presented mathematical tasks necessary for developing a good foundation in problem solving. The tasks in the books required students to apply conceptual knowledge to solve multi-step and challenging problems using a variety of heuristics, thereby facilitating the development of logical and higher order thinking skills. In a comparative study of lower secondary (grade 8) textbooks from Singapore, China and the United States, Fan and Zhu (2007) found that there were gaps between the national syllabuses and textbooks in Singapore although the textbooks were tightly aligned to the syllabuses. They found that the textbooks failed to demonstrate the heuristic "thinking of a related problem", which was stipulated in the syllabuses. Also there was little illustration of the stage of "looking back" in problem-solving procedures even though the syllabuses placed importance on developing students' metacognition. Kaur (2010) studied mathematical tasks used in their lessons by three teachers who were recognised for their teaching competency in their respective schools. She found that although textbooks used in Singapore schools must have approval from the Ministry of Education and satisfy the curriculum content requirements, they have their limitations too. The study found that although problem solving was the official end goal of both instruction and assessment as stipulated by the framework for the school mathematics curriculum, the instructional practice and assessment practice of the three classrooms appeared to be poorly aligned with this goal.

One significant study by Hogan et al. (2013), that was not about enactment of a problem-solving curriculum in Singapore schools, assessed the quality of the enacted curriculum in Secondary 3 (grade 9) mathematics. The study involved a large representative sample of schools in Singapore using criteria and standards identified by Hattie in *Visible Learning* (2012). The findings suggested that teachers focused more on procedural knowledge than conceptual knowledge and only engaged students in domain-specific knowledge practice in about a third of the phases of a typical lesson. Of the domain-specific knowledge practices, knowledge representation was emphasised. They also found that epistemic talk – systematic talk about knowledge that is critical to visible teaching and learning and to enhancing student understanding and skill formation – was lacking in the lessons. There was also lack of formative monitoring that could make student learning visible. Instead, procedural learning support was evident as teachers often helped with the "how to do" steps.

It appears from the above that the few research studies published on the enactment of the school mathematics curriculum in Singapore appear to have a narrow focus. In the context of Remillard and Heck's framework, the research mainly deals with how the designated curriculum may be enacted to achieve the curricular aims and objectives and the alignment of the instructional materials (mainly textbooks) also with the curricular aims and objectives. However, to say that these are the only two possible research directions pursued may be incorrect as schools do carry out their own investigations to study the impact of instructional materials, mainly textbooks, on the enactment of the curriculum and student outcomes. Their investigations may not be highly rigorous but they do need these kinds of findings to make decisions about the textbooks teachers would adopt for the mathematics programmes at their schools.

Schools also carry out focused experiments on pedagogies to address specific needs of their students. The findings help them to improve on the enactment of the curriculum for student learning. Again they do not publish such work and therefore we are not able to document it. Every six years the school mathematics curriculum is revised, and again several sources of data and knowledge input into the revision. One such source of data is the international benchmark studies, TIMSS and PISA, which Singapore participates in. For example, Kaur (2013) noted that, following a study of how students from Singapore at the eighth grade level performed in TIMSS during the cycles of 1995, 1999 and 2003, the curriculum specialists convinced the Ministry of Education to introduce the topic of probability at grade 7 in 2006. Prior to 2006, probability was introduced to students only in grade 9.

Considering all the investigative work undertaken by educators in Singapore related to the enactment of school mathematics curriculum, it may be said that the conceptual model proposed by Remillard and Heck (2014) is rigorous. The issues raised in this particular issue of *ZDM* do offer educators and researchers very good perspectives for research on the enactment of the curriculum, though some ideas may be virtually impossible to test in the context of the national system of schooling of Singapore. One such direction for research would be work similar to that of Confrey et al. (2014) on learning trajectories – connecting standards with curriculum. In the official curriculum of school mathematics the learning trajectories are specified in the detailed syllabuses by grade levels. Textbooks are bound by the sequence of these trajectories and therefore it would be virtually impossible to find a research site to carry out such a research study as the national examinations also are connected to the learning trajectories. In addition, when teachers find that these trajectories generally work, they are reluctant to engage in experiments with the researchers.

The works by Remillard et al. (2014), Huntley and Terrell (2014), and Sears and Chávez (2014) on the influence of curriculum material design on opportunities for student learning offer researchers frameworks for the study of the intent of various textbook series used in Singapore schools. These books are produced by commercial publishers but with guidance from the curriculum specialists in the Ministry of Education in Singapore. Several series of textbooks are approved for use in schools and schools decide on the series to adopt. As mentioned before, schools do carry out some investigations before deciding on their choices. Perhaps such research could offer schools rigorous data and findings to aid their decisions for adoption of textbooks.

With regard to the development of teachers associated with the enactment of the school mathematics curriculum, studies reported in this issue (Remillard et al. 2014; Thompson and Senk 2014; Sears and Chávez 2014; Otten and Soria 2014) offer researchers excellent leads on not only the potential of curriculum materials but also how this potential may or may not be actualised during classroom enactment. Very often, at the same grade level in a school, student learning is an issue to address as the same materials are used across the classes and yet student outcomes may be significantly disparate.

Wong, a teacher with twenty years of classroom teaching experience in a secondary school and also a recipient of the President's award for teachers, noted that "other than drawing on past national examinations and school examinations test items, teachers too use some of the assessment items provided by the textbook publishers, when designing their classroom assessments" (Wong, 2014, p 11). There appears to be no study that has scrutinised what these assessment items in published textbooks place emphasis on. The study by Hunsader et al. (2014) does raise a thought "Do teachers in Singapore use the assessment items in their textbooks as a primary means to evaluate students' mathematical knowledge?" The author's perception of these assessment items in the textbooks is that they are often merely used as homework assignments so that students hone their examination preparation skills. It would certainly be of interest to researchers in Singapore to study how these assessment items align with the mathematical processes outlined in the framework for school mathematics in Singapore.

4.0 Concluding Remarks

In this section we summarise our thoughts about the questions we set out to answer in this paper.

To what extent are the conceptual model proposed by Remillard and Heck and other issues raised in this issue of ZDM applicable to the kinds of research done in Singapore?

It is apparent from the published research and unpublished investigative studies often carried out by schools and the Ministry of Education curriculum specialists that the conceptual model proposed by Remillard and Heck (2014) is rigorous for our work in Singapore. The model shows how the official curriculum and the inter-relationships between aspects of them may be operationalised. With the goal of improving classroom instruction it is pertinent for teachers and researchers in Singapore schools to research the bi-directional relationships between teacher intended curriculum, enacted curriculum and student outcomes as shown in Remillard and Heck's model. In addition, studies reported in this issue of *ZDM* (Remillard et al. 2014; Huntley and Terrell 2014; Sears and Chavez 2014; Thompson and Senk 2014; Otten and Soria 2014) offer researchers excellent leads on not only the potential of curriculum materials but also how this potential may or may not be actualised during classroom enactment.

How prescriptive is the national curriculum? What information is available about how the curriculum is enacted? Is the curriculum enactment discussed or even a research issue?

We may say that the national curriculum for mathematics in Singapore schools is very comprehensive. One may also claim that it is prescriptive in some ways; for example, as shown in Tables 1 and 2, it outlines in detail the learning trajectories by grade level, stating clearly the learning experiences that are necessary for students to engage with. There appears to be a dearth of published research on the enactment of the curriculum, though the author is aware of unpublished, not so rigorous, research that takes the form of focused investigations at the school level to guide school teachers in their choice of textbooks and also classroom pedagogies for improved student learning. It may be said that curriculum enactment is a key issue of discussion amongst curriculum specialists at the Ministry of Education and focused group discussions at the Mathematics chapter of the Academy of Singapore Teachers. In schools often during professional learning meetings the enactment of the curriculum is also discussed. However, during these discussions educators draw more often on their tacit knowledge than rigorous research projects. In some ways, the element of time plays a huge part in this matter. For a rigorous project to be implemented and data collected often a good span of time is needed. At meetings the collective experiences of teachers often provide instant data that guide new hypotheses which are again tested in the same manner. So, this quick cycle often overshadows the discussion for carrying out rigorous research to address issues faced when enacting the curriculum.

Lastly, it is worthy to note that when we study the enactment of curriculum within a country, any model developed has the potential for contributing to work in other countries. However, to adopt a model and do a comparative study often proves challenging as the country level variables, such as centralised and non-centralised curricula, and ability-based curricula, are often not easy to compare. Furthermore, different challenges pose different priorities in countries.

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