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Use of Real-World Contexts in Instructional Materials Designed by Pre-University Mathematics Teachers

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ABSTRACT

Pre-university education in Singapore serves as a bridge between secondary and university education. Despite its importance in the Singapore education system, few studies have been conducted on Singapore pre-university mathematics. We also notice that problems in real-world contexts have been increasingly emphasized in the Singapore mathematics curriculum. In this paper, we study the infusion of real-world contexts in the design of instructional materials in a typical pre-university institution, with a focus on the topic of vectors. The real-world contexts used in the instructional materials are categorized into neutral contexts or real-life experiences, where each of these categories has their benefits. These include the potential to raise students' awareness that mathematics can be used to solve real-world problems and explain real-world phenomena. Their alignment to the Singapore mathematics syllabus and 21st Century Competencies is also discussed.

Keywords: Pre-university mathematics, real-world contexts, instructional materials, vectors

INTRODUCTION

Pre-university education in Singapore caters to grade 11 to 12 students; it follows secondary education and precedes university education. It is one of the major and most common pathways for students to qualify for local and overseas university admission. Similar to secondary education, learning is predominantly facilitated by the teachers. All the pre-university institutions deploy the same lecture-tutorial mode of instruction, and it is the first time that post-secondary education students are exposed to such a mode of instruction. This enables them to be accustomed to such a teaching and learning style which is commonly used in university education.

Students undergoing pre-university education in Singapore have autonomy to choose their preferred subjects; mathematics is chosen as a subject by the majority of students. Despite the importance of pre-university education, very few studies have been conducted on pre-university mathematics in Singapore. Some of the available literature include a case study of the calculus Instructional Materials (IMs) from a pre-university institution [1], and students' performance in different mathematics tasks [2], [3], [4]. However, the education literature in this field is lacking especially in comparison with research in the teaching and learning of mathematics at the primary and secondary levels [5], [6], [7], [8], [9], [10], [11].

Additionally, there is an absence of a standardised textbook for pre-university mathematics education in Singapore. In comparison, the Ministry of Education (MOE) publishes an approved textbook list for primary and secondary mathematics education [12]. Anecdotal evidence from primary and secondary schools in Singapore suggests that a textbook is an essential IM in mathematics education in schools. This is supported by Fan's [13] assertion that Singapore's mathematics textbooks are "a most important resource in support of teaching and learning in mathematics classroom" (p. 1). Due to the absence of a textbook at the pre-university level, each pre-university institution in Singapore develops her mathematics IMs based on her interpretation of syllabus documents, and the IMs play the role of textbooks to complement the teaching and learning of mathematics. This is consistent with Fan's [13] suggestion that textbooks are a reflection of textbook writers' interpretation of the curriculum and syllabus.

Background

We utilise an operational definition of IMs as "classroom-ready materials that teachers incorporate into their lessons for students' direct access for their learning" [14, p. 79]. In the context of pre-university education in Singapore, the term IMs refer to lecture notes and tutorial exercises.

In this paper, we aim to answer the research question: how are real-world contexts utilised in the IMs? This paper reports a part of a larger study by us that analyses the IMs designed by pre-university mathematics teachers. In this paper, we focus on the use of real-world contexts in the IMs. We utilise a case study approach, where we study the IMs of a typical pre-university institution on the topic of vectors. An experienced teacher from the pre-university institution was interviewed to validate our findings. Note that the findings from this study may not be representative of all the pre-university institutions as different institutions might interpret the syllabus in their unique way and have varying focus areas [15], [16], [17].

Literature Review

Singapore Mathematics Curriculum Framework

The Singapore Mathematics Curriculum Framework is an integral component of mathematics education from the primary to pre-university levels in Singapore; it is a common feature in syllabus documents across the levels [18], [19], [20]. **Figure 1** illustrates this framework. It "sets the direction for and provides guidance in the teaching, learning, and assessment of mathematics" [18, p. 3]. From the pentagon framework, five components, namely attitudes, metacognition, skills, processes, and concepts support the enactment of mathematical problem solving [18].

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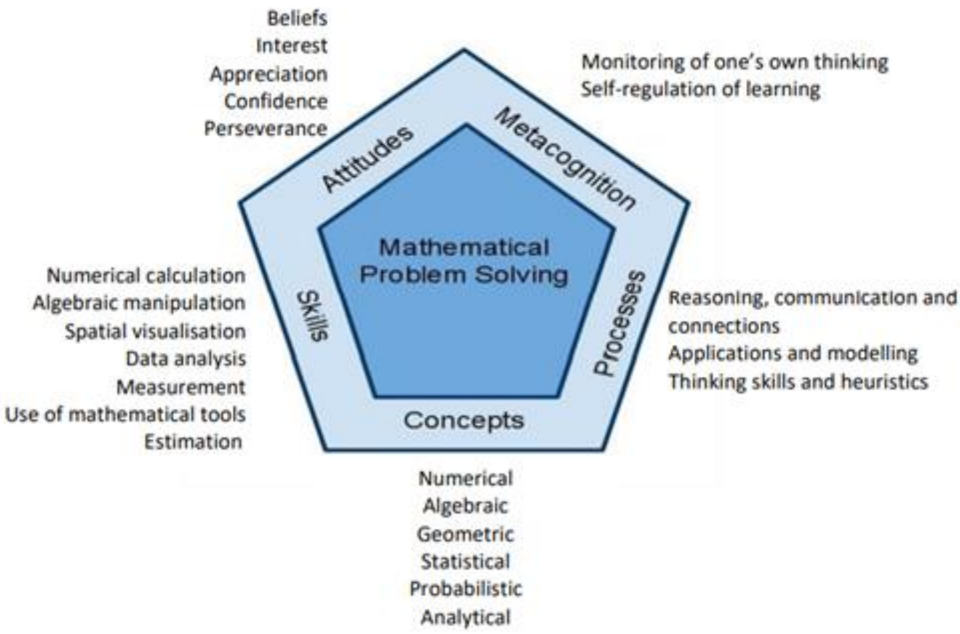

Figure 1. Singapore Mathematics Curriculum Framework [18].

Extended Singapore Mathematics Curriculum Framework [21]

Wong [21] observed that the main features of the Singapore Mathematics Curriculum Framework had remained since its inception, even after reviews of the framework were carried out. To meet the growing focus by MOE at that time on real-life applications, he proposed an extended Singapore Mathematics Curriculum Framework, where he introduced a new component of "context knowledge" [21]. **Figure 2** illustrates the hexagonal framework proposed by Wong [21]. Wong [22] suggested that mathematics problems have the potential to enable students to gain new insights about its contexts, which will allow them to "understand their environments through mathematical lenses" (p. 133). Context knowledge hence refers to real-world, non-mathematics related, knowledge that is required to understand these mathematics problems [22].

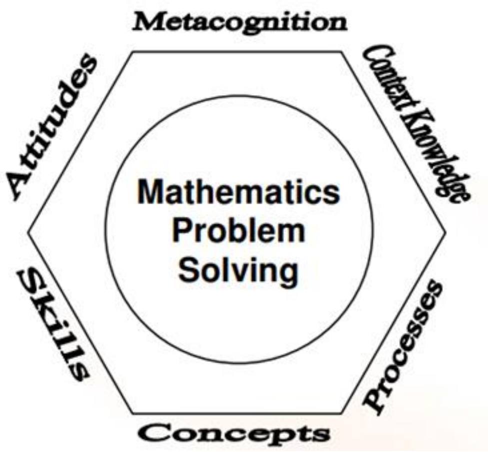

Figure 2. Extended Singapore Mathematics Curriculum Framework [21].

Wong [21] illustrated "context knowledge" through various examples: neutral contexts, basic real-life experience, conflicting contexts and domain-specific knowledge.

Two of such context knowledge are exemplified as follows: neutral contexts refer to contexts that are easily interchangeable, such as objects or people, whereby changing the context does not alter the composition of the problem, while basic real-life experiences refer to the knowledge of common experiences one would encounter in daily-life and suitable assumptions that are made in these situations [21]. Although Wong's extended Singapore Mathematics Curriculum Framework has not been adopted as the official mathematics curriculum framework, its assertions on context knowledge are still relevant in today's contexts as real-life applications remain a focus by MOE today; the pre-university mathematics syllabus is designed such that students are exposed to the applications of mathematics and the "connections to other disciplines and to the real world" [18, p. 3].

21st Century Competencies (21CC) [23]

MOE has conceptualised a Framework for 21CC and Student Outcomes to aid students in being successful in this volatile world and to serve as a foundation for students' holistic education [23]. **Figure 3** illustrates this framework. One of the 21CC proposed by MOE [23] is critical and inventive thinking, and it has been suggested that mathematics at the pre-university level "supports the development of 21CC" as it has the potential to provide students with opportunities to engage in critical thinking [18, p. 6]. Although MOE's interpretation of critical and inventive thinking is not explicitly stated [23], we can understand it to comprise components such as "managing complexities and ambiguities", "curiosity and creativity" and "reflective thinking", as stated in a presentation by an MOE specialist [24, p. 8].

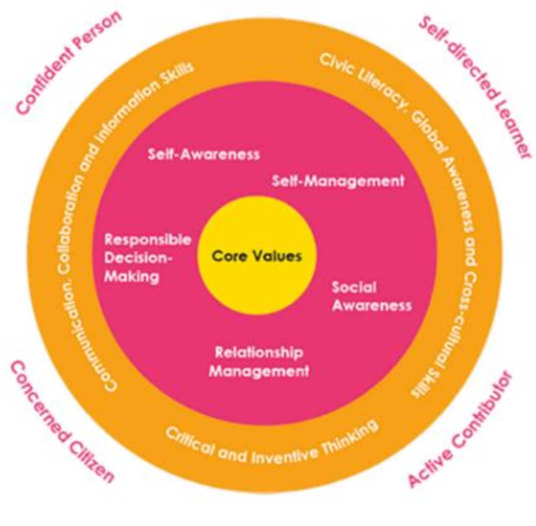

Figure 3. Framework for 21CC and Student Outcomes [23].

MATERIAL AND METHODS

A case study approach was utilised in this study, where a pre-university institution that has been established for more than 40 years consented to be part of this study. We studied the lecture notes of the chapter on Vectors and its corresponding tutorial exercises consisting of three sections: 3A (algebra of vectors), 3B (vector equations of lines) and 3C (vector equation of planes). We identified the sections in which real-world contexts were present and these are presented in **Table 1**. Teacher Lawrence (pseudonym), who has been involved in the development of the IMs produced by the institution and who is a senior teacher by appointment, was identified and voluntarily participated in an interview session with us to verify our findings.

Table 1. Sections of the IMs in which real-world contexts were present.

No.	IM	Mathematics Concept(s)	Real-World Context(s)
1	Lecture notes 3.1.4.4	Resultant vector	Description of a car journey between towns
2	Lecture notes Example 3.2	Unit vector	Velocity of an airplane
3	Lecture notes Example 3.25	Problems involving a point and a line	Velocity and position of a space shuttle and station
4	Lecture notes Example 3.53	Miscellaneous concepts	Position of flagpoles and ropes
5	Tutorial exercise 3A Question 6	Algebra of vectors	Velocity and position of a plane
6	Tutorial exercise 3A Question 12	Algebra of vectors	Vectors in nature (rain)
7	Tutorial exercise 3A Assignment question 1	Algebra of vectors	Speed of aircraft and position of aircraft, transmitters, and control tower
8	Tutorial exercise 3B Question 8	Vector equations of lines	Electrical engineers and electricity cables
9	Tutorial exercise 3B Question 9	Vector equations of lines	Comets and planets in space
10	Tutorial exercise 3C Question 11	Vector equations of planes	Design of an art museum
11	Tutorial exercise 3C Assignment question 2	Vector equations of planes	Manufacturing of circuit boards

RESULTS AND DISCUSSION

We categorise the real-world contexts present in the IMs into two categories: neutral contexts and basic real-life experiences, aligned to Wong's [21] illustration of context knowledge.

Neutral Contexts

The real-world contexts excluding No. 6 and 11 listed in **Table 1** can be classified under neutral contexts. In these contexts, we observe that changing the real-world object will not alter the composition of the problem [21]. For example, real-world context No. 7, illustrated in **Figure 4**, can be changed, where a plane can be substituted with a space shuttle, transmitters can be substituted with satellites or planets, and the problem and solution will remain essentially the same. Our observation that almost all the real-world contexts used in the IMs are of the form of neutral contexts is consistent with Wong's [22] assertion that "many word problems are of this kind" (p. 134).

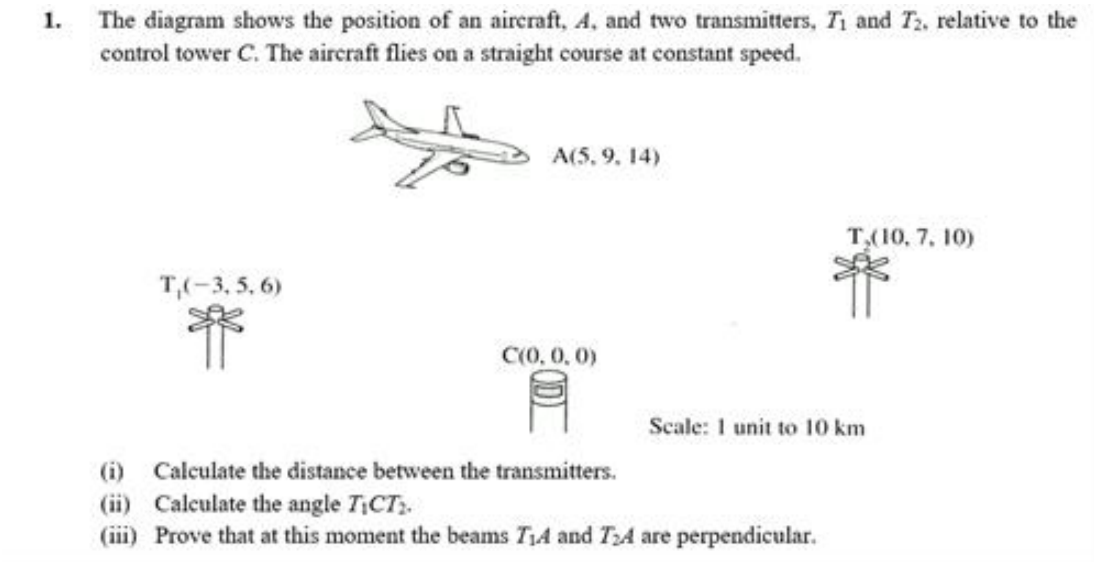

Figure 4. Neutral context of an aircraft, transmitters, and control tower.

It can also be observed from **Table 1** that contexts commonly utilised involve airplanes or objects in space. This could possibly be because one of the sub-topics of vectors at the pre-university level is vector geometry in three-dimensions [18], and these contexts serve as word problems catering to this sub-topic. In these problems, no external real-world knowledge is required as the context and assumptions of the problem are clearly stated. We suggest that for students, apart from being able to apply the mathematics content they have learnt to solve the problem, there is no other added value of the context. This is consistent with Wong's [22] assertions that in word problems involving neutral contexts, students do not require extensive real-world knowledge to solve them, and after exposure to such problems, they do not acquire new information about the world. Hence, we suggest that teacher practitioners can consider incorporating problems involving such neutral contexts if their intention is to solely allow students to directly apply their newly acquired mathematics knowledge on an arbitrary question, where the context has no added value or purpose.

We observe that Wong [21], [22] did not explicitly mention any benefits of utilising problems involving neutral contexts. However, we assert that there is value in incorporating problems involving a certain category of neutral contexts- that involves the solving of real-world problems. Real-world contexts No. 4 and 8 fall under the above-mentioned sub-category of neutral contexts. For example, in real-world context No. 8, illustrated in **Figure 5**, students are required to solve a real-world problem on the installation of cables by engineers. It is a neutral context because for example, the context of engineers installing cables can be changed to that of an event organiser laying ropes across an event venue, and the composition of the problem will stay the same. Additionally, assumptions are clearly stated in the question. This is similar to the structure of real-world context No. 7 shown in **Figure 4**. However, we observe that an additional feature of this word problem is that it is contextualised in an actual potential real-world problem. As such, we suggest that it is implicitly suggested to students that real-world problems of a similar structure can be solved using similar mathematics concepts, in this case, by considering the position of real-world objects relative to a reference point and using vector concepts.

8. [H2 Math 2017/I/10]
Electrical engineers are installing electricity cables on a building site. Points (x, y, z) are defined relative to a main switching site at $(0,0,0)$, where units are metres. Cables are laid in straight lines and the widths of cables can be neglected.

An existing cable C starts at the main switching site and goes in the direction $\begin{pmatrix} 3 \\ 1 \\ -2 \end{pmatrix}$.

A new cable is installed which passes through points $P(1,2,-1)$ and $Q(5,7,a)$.

(i) Find the value of a for which C and the new cable will meet.

To ensure that the cables do not meet, the engineers use $a = -3$. The engineers wish to connect each of the points P and Q to a point R on C.

(ii) The engineers wish to reduce the length of cable required and believe in order to do this that angle PRQ should be 90°. Show that this is not possible.

(iii) The engineers discover that the ground between P and R is difficult to drill through and now decide to make the length of PR as small as possible. Find the coordinates of R in this case and the exact minimum length.

Figure 5. Neutral context (real-world problem) of electrical engineers and electricity cables.

Through exposure to such questions, we suggest that positive attitude in mathematics can be fostered in students, where they believe in the usefulness of mathematics, because they are exposed to the idea that mathematics knowledge can be used as a tool to solve some real-world problems. This is in alignment with the curriculum goals as stated in the Singapore Mathematics Curriculum Framework [18]. Therefore, we assert that teacher practitioners can consider utilising word problems of such contexts if they want students to apply their newly learnt mathematics knowledge on a real-world problem, without the need for external knowledge about the context, and be aware that mathematics can be used as a resource to solve some real-world problems. It should be noted that students might not be immediately apparent of such a resource; hence, it is recommended that teacher practitioners facilitate this process.

Basic Real-Life Experiences

In this section, we discuss two different types of problems involving contexts of basic real-life experiences: one of which involves the context of real-world problems, and the other involves the context of real-world phenomena.

In real-world context No. 11, illustrated in **Figure 6**, students are required to find an expression for the number of circuit boards A, B and C that are manufactured given resource limitations and considerations. To answer this question accurately, students are required to utilise their prior real-life knowledge to deduce that the number of circuit boards that are manufactured is a non-negative integer.

A technology company specialises in manufacturing circuit boards that are used for space exploration. It manufactures only 3 types of circuit boards (A, B and C). Each circuit board requires particular amounts of different raw materials for manufacturing. The amounts of raw material (in units) required for each type of circuit board and the total amounts of raw material available to the company are shown in the following table.

	Copper	Lead	Fibreglass
Circuit Board A	1	4	2
Circuit Board B	2	5	3
Circuit Board C	1	10	4
Total amount of material available (in units)	60	180	100

The company is required to use all the materials available to manufacture its circuit boards.

The vector $\mathbf{r} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$ is defined such that variables x, y, and z represent the number of circuit boards A, B and C that are manufactured respectively.

(iii) With the aid of your answer in part (i), solve for $\mathbf{r}$. Leave your answer clearly in the form of $\mathbf{a} + \mu\mathbf{b}$ and state the possible values for μ.

(iv) Explain, in context, why your vector equation in part (i) is not an appropriate answer for part (iii).

Figure 6. Basic real-life experience (real-world problem) of the manufacturing of circuit boards.

This aligns to Wong's [21] exemplification of basic real-life experiences, where he gave an example of students requiring context knowledge from their basic real-life experiences (e.g., number of buses are counted in whole numbers) to avoid the use of fractional answers (e.g., 12.3 buses) when whole numbers should be used in the context. This question enables students to solve a real-world problem: that of a manufacturing resource problem. Similar to the case of neutral context involving real-world problems, we suggest that exposure to such questions exposes students to the knowledge that mathematics can be used as a tool to solve real-world problems, aligned to the "attitudes" component in the Singapore Mathematics Curriculum Framework [18]. Furthermore, we assert that this question provides students with the opportunity to engage in reflective and hence critical thinking [24] because students are explicitly suggested to reflect on the appropriateness of the answers that they have obtained to the real-world problem in part (iv) of the question. Hence, we suggest that teacher practitioners can consider the use of word problems involving such contexts if the aims of the problem are to increase students' awareness of mathematics as a real-world problem solving resource and to enable students to utilise some of their basic real-life experiences and knowledge to engage in reflective and critical thinking. We urge teacher practitioners to be mindful of the basic real-life experiences and knowledge chosen when conceptualising such questions to avoid situations whereby some students have insufficient knowledge of the contexts.

Real-world context No. 6, illustrated in **Figure 7**, involves a phenomenon that students can directly observe in their daily lives. To solve the question, students are required to consider different scenarios, one of which is when the bus is moving and the other, of which the bus is stationary, and explain their observations.

12. (Vectors in Nature)
You were travelling in a bus on a rainy day. You looked out the window and saw the rain appeared slanted towards you but when the bus came to a stop, the rain appeared vertical. Explain this phenomenon using vectors.

Fig. 7. Basic real-life experience (real-world phenomenon) of vectors in nature.

Assumptions are implicitly present in the question. For example, the assumption of the absence of wind leads to the rainfall appearing vertical. Otherwise, the phenomenon of vertical rainfall is not generally true. This is consistent with Wong's [21] exemplification of basic real-life experiences and implicit contexts [22], where he suggested that in some of the questions involving these contexts, implicit assumptions, sometimes unrealistic ones, are present in the questions and are pivotal to solve the question [21], [22]. In this question, implicit assumptions are present in the question to allow students to explain the real-world phenomenon in a simplified way. Students are required to utilise their real-world experience and knowledge to deduce the implicit assumptions made in the question.

In our interview with teacher Lawrence, after he verbally shared real-world context No. 6 with us, we asked him for his views on whether he believed that the real-world context had enabled his students to better appreciate what they are learning, to which he agreed, *"because you (i.e., teachers) are relating something, you know, mathematical, er, and abstract to something that they (i.e., students) observe in, er, in real-life"*. He then shared some of his curricular goals, which is that he *"want[s] them to see that mathematics is not something that is confined to the classroom, you see it everywhere"*. Additionally, he *"want[s] them (i.e., students) to put on that mathematical lens when they look at the world, then they can, they can explain, you know, the phenomenon, why is, why does the rain appear slanted."* As such, it can be inferred that from the perspective of the teachers, one of the intentions of incorporating real-world context No. 6 in the IMs is to encourage students to look beyond the use of mathematics purely in classroom settings, to the world outside, to explain real-world phenomena. Hence, we assert that this is aligned to the Singapore Mathematics Curriculum Framework [18] as exposure to questions like this has the potential to develop positive attitude towards mathematics in students, where they can appreciate the "beauty and power of mathematics" [18, p. 5] because they are aware that mathematics can be used in everyday life, not only to solve real-world problems as discussed in the previous section, but to be able to explain real-world phenomena.

Furthermore, we assert that problems involving real-world contexts such as No. 6 provide students the opportunity to engage in critical thinking. This is because such problems require students to infer the implicit assumptions present and make these assumptions in their solution. Also, the problem presents students with a relatable real-life scenario (i.e., sitting on a bus when it is raining) with differing real-life observations (i.e., rain falling in a different manner) in different contexts (i.e., when the bus is moving compared to when the bus comes to a stop); as such, we suggest that there is potential that curiosity is invoked in students as they seek to explain the differing observations in their daily lives. Making assumptions is a sub-element of critical and inventive thinking while curiosity is suggested to be an element of critical and inventive thinking [24]. As such, we assert that problems of such contexts are aligned to MOE's Framework for 21CC and Student Outcomes [23]. Therefore, we suggest that teacher practitioners can utilise word problems of such contexts if their curricular aims include increasing students' awareness that mathematics can be utilised to explain real-world phenomena in their everyday lives, encouraging students to be comfortable with deducing and making appropriate assumptions in word problems, and to be curious about linking real-world phenomena with mathematics knowledge.

CONCLUSIONS

This study provides insight on the utilisation of real-world contexts in the IMs of a pre-university institution in Singapore. We utilised Wong's [21], [22] description and exemplification of context knowledge to categorise the real-world contexts used in the IMs and discussed the value of these contexts in relation to the Singapore Mathematics Curriculum Framework and 21CC. This will provide teacher practitioners a more goal-driven approach in infusing real-world contexts in the conceptualisation and development of their IMs, while aligning to their curricular goals.

It should be noted that this study involved the analysis of the IMs of a pre-university institution on the topic of vectors; hence, limitations of this study include the scope of analysis in terms of topics in the pre-university mathematics syllabus and the number of pre-university institutions studied. Hence, the results might not be representative of the general pre-university mathematics education scene in Singapore. It is hoped that this study motivates further in-depth research in the study of IMs; we are currently conducting a comprehensive study on the alignment of IMs to the pedagogies in the Singapore mathematics curriculum.

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