ASSESSING GEOMETRICAL MEASUREMENT SKILLS AMONG YEAR FIVE NATIONAL SCHOOL PUPILS

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by

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LIST OF ABBREVIATIONS

Ave	Average of Relevance Rating by Individual Expert
CMIM	Count Me into Measurement
CTT	Classical Test Theory
CVI	Content Validity Index
DGF	Differential Group Functioning
DIF	Differential Item Functioning
EPRD	Educational Planning and research Division
GMSI	Geometrical measurement skills Instrument
I-CVI	Item Content Validity Index
IRT	Item Response Theory
JEPeM	*Jawatankuasa Etika Penyelidikan Manusia Universiti Sains Malaysia*
KPM	Kementerian Pendidikan Malaysia
MeSA	Measurement Skills Assessment
MNSQ	Mean Square
MOE	Ministry of Education
NCRMSE	National Centre for Research in Mathematical Sciences Education
PCA	Principal Component Analysis
PCM	Partial Credit Model
PIDM	Person- Item Distribution Map
PISA	Programme for International Student Assessment
PT- MEASURE	Point Measure
Q-Q Plot	Quantile- Quantile Plot
Quan- qual	Quantitative- qualitative Method
S-CVI	Scale Content Validity Index

SOLO	Structure of the Observed Learning Outcome
SOP	Standard Operation Procedure
SPSS	Statistical Packages for Social Sciences
TIMMS	Trends in International Mathematics and Science Study
UA	Universal Agreement
UPSR	*Ujian Pencapaian Sekolah Rendah*
ZSTD	Normalized and Standardized Infit and Outfit

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MENTAKSIR KEMAHIRAN PENGUKURAN GEOMETRI DALAM KALANGAN MURID TAHUN LIMA DI SEKOLAH KEBANGSAAN

ABSTRAK

Pengukuran geometri bukan sahaja merupakan topik yang penting dalam subjek matematik, malah ia berfungsi sebagai asas kepada displin lain seperti fizik, kimia, biologi, dan geografi. Tambahan pula, pengukuran geometri telah diperkenalkan kepada murid sejak tahun pertama sekolah rendah dan dinilai dalam peperiksaan antarabangsa dan awam. Walau bagaimanapun, pengukuran geometri dilaporkan sebagai salah satu topik yang paling mencabar dalam matematik sekolah rendah kerana kebanyakan murid mempunyai kefahaman yang tidak mencukupi disebabkan oleh amalan pembelajaran menghafal formula tanpa memahami konsep asas. Kajian lalu telah menunjukkan bahawa faktor kefahaman yang rendah terhadap pengukuran geometri adalah disebabkan oleh kurangnya penilaian kemahiran pengukuran geometri. Oleh itu, kajian ini dijalankan untuk membangunkan rangka kerja pentaksiran dan Instrumen Kemahiran Pengukuran Geometri (GMSI) untuk menilai kemahiran pengukuran geometri murid Tahun Lima. GMSI telah dibangunkan dengan menggunakan Taksonomi SOLO dalam format super item, yang menekankan tahap hierarki kesusahan item untuk memastikan instrumen meliputi kedua-dua peringkat iaitu peringkat mudah dan susah. Data daripada 500 murid telah dikumpul dan dianalisis secara kuantitatif menggunakan analisis Rasch untuk meneliti ciri-ciri psikometrik, memprofilkan item dalam GMSI dan mengenal pasti perbezaan jantina. 20 orang murid telah dipilih secara bertujuan untuk analisis kualitatif menggunakan analisis tematik untuk mengesahkan rangka kerja penilaian dan mengenal pasti corak kesilapan murid. Keputusan menunjukkan bahawa GMSI memenuhi ciri-ciri psikometrik, dan deskriptor rangka kerja penilaian kelihatan selari dengan respons murid, menunjukkan bahawa GMSI adalah sah dan boleh dipercayai. Selain itu, hasil analisis PIDM menghasilkan profil dari segi kesukaran item dan keupayaan murid mengikut tahap Taksonomi SOLO. Hasil analisis ujian-t dan kefungsian kumpulan pembezaan menunjukkan bahawa tidak terdapat perbezaan yang signifikan antara murid lelaki dan perempuan dalam kemahiran pengukuran geometri, kemahiran spasial dan kemahiran numerikal. Tambahan pula, analisis tematik menemui corak ralat pada setiap tahap Taksonomi SOLO. Secara keseluruhannya, GMSI telah menyumbang kepada pembangunan dan pengesahan instrumen baharu dengan menggunakan konstruk yang baharu ditakrifkan dan penyepaduan tahap pemahaman Taksonomi SOLO. Justeru, kajian ini dapat membantu guru dan murid dalam mendiagnosis kekuatan dan kelemahan pengukuran geometri dan merancang pemulihan yang sistematik untuk menambah baik pengajaran dan pembelajaran. Walaupun GMSI didapati sah dan boleh dipercayai, kajian masa depan boleh dilakukan untuk menambah baik seperti menambah lebih banyak item, mengembangkan kepada murid menengah dan mentadbir instrumen dalam talian dengan maklum balas diberikan kepada murid.

ASSESSING GEOMETRICAL MEASUREMENT SKILLS AMONG YEAR FIVE NATIONAL SCHOOL PUPILS

ABSTRACT

Geometrical measurement is an important topic in mathematics that serves as the foundation for other disciplines such as physics, chemistry, biology, and geography. Furthermore, geometrical measurement has been introduced to pupils since the first year of primary school and is assessed in international and public examinations. However, geometrical measurement is reported to be one of the most challenging topics in primary mathematics since most pupils have inadequate understanding due to the learning practice of memorizing formulas without grasping the underlying concepts. Research has shown that factors of low understanding of geometrical measurement is due to the lack of assessment of geometrical measurement skills. Therefore, this study is conducted to develop an assessment framework and Geometrical Measurement Skills Instrument (GMSI) to assess Year Five pupils' geometrical measurement skills. GMSI was developed by applying SOLO Taxonomy in the super item format, that emphasizes the hierarchical level of complexity of the items in order to ensure that the instrument covers both surface and deep level items. Data from 500 pupils were collected and analyzed quantitatively using Rasch analysis to examine the psychometric properties, profile the items in GMSI and identify the gender differences. 20 pupils were purposively selected for the qualitative analysis using thematic analysis to validate the assessment framework and identify the error patterns. The results revealed that GMSI met the psychometric properties, and the assessment framework's descriptors appeared to agree with the pupils' responses, indicating that GMSI is valid and reliable. Also, the results of PIDM analysis produced

a profile in terms of item difficulty and pupil ability according to SOLO Taxonomy level. Besides, the results of t-test analysis and differential group functioning indicated that there was no significant difference between male and female pupils in geometrical measurement skills, spatial skills and numerical skills. Furthermore, the thematic analysis discovered the error patterns at each of the SOLO Taxonomy level. Overall, GMSI has contributed to the development and validation of a new develop instrument by the use of newly defined constructs and the integration of SOLO Taxonomy level of understanding. Thus, this study could assist teachers and pupils in diagnosing the strengths and weaknesses of geometrical measurement and planning systematic remedies to improve teaching and learning. Although GMSI was found to be valid and reliable, future research could be done to improve such as adding more items, expand to secondary pupils and administer the instrument online with feedback given to pupils.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The word geometry is derived from the Greek word's "geo" and "metric" where "geo" means earth and "metric" means "measure". Geometrical measurement is related to geometry and measurement (Wickstrom et al., 2017). Geometrical measurement is an essential area in children's development and can be defined as perimeter, area, and volume measurement in one, two and three dimensions, respectively (Fuson et al., 2010; Kim et al., 2017). It is a crucial topic because it connects mathematics to the real world and serves as the foundation for number lines, multiplication arrays, fractions and graphs. Aside from that, it stands as the important basis for studying other topics such as physics, chemistry, biology, geology and geography, as well as art and architecture (Fuson et al., 2010). As a result, understanding geometrical measurement in both conceptual area and skill is critical (Clements & Battista, 2001). Therefore, it is not surprising that geometrical measurement has been introduced since pre-school, developed and expanded throughout the primary years (Outhred & McPhail, 2000). However, Jones and Tzekaki (2016) mentioned that, pupils obtain low achievement and confusion in understanding the concept of geometrical measurement in various aspects such as units, partition or iteration. According to Tůmová and Vondrová (2017) and Vasilyeva et al. (2009a), pupils can grasp the underlying concepts of geometrical measurement if pupils have a high level of geometrical measurement skills.

Geometrical measurement skills may seem to be a rather limited component of mathematical knowledge, but it is one of the most commonly used applications of mathematics in daily life and plays a distinctive role in both mathematical and other topics such as science and technology (Baroody et al., 1998; Lehrer et al., 2003). In order to understand geometrical measurement more abstractly, students need to acquire both spatial and numerical skills, in which they need to visualise and create spatial structuring in an appropriate manner, and begin to formulate and abstract the enumeration process in terms of formulas (Kim & Oláh, 2019). Therefore, geometrical measurement skills involve the integration of spatial and numerical skills (Kim et al., 2017; Kim & Oláh, 2019; Tůmová & Vondrová, 2017; Vasilyeva et al., 2009a; Vasilyeva et al., 2009b). However, Crites et al. (2018), Hannighofer et al. (2011), Vasilyeva et al. (2009) mentioned in their study that there was a lack of assessment of the skills associated with conceptual understanding of geometrical measurement.

Therefore, one of the ways to ensure that pupils acquire the skills needed and to obtain deeper understanding on pupils' level of geometrical measurement skills in geometrical measurement is through the implementation of a good assessment practises. Assessment is one of the key components of teaching and learning processes. Assessment has an important role to play in achieving the learning objectives. This is because assessment is used for monitoring learning progress, learning outcomes, and sustainably detecting remedy needs for pupils from the learning outcomes (Muklis et al., 2018). Besides that, the teachers can ameliorate the misconceptions and weaknesses of the pupils and enhance their teaching skills at the same time. In line with the importance of educational assessment, researchers are continuously designing new approaches to optimize assessment efficiency (Wu & Adams, 2006). Therefore, assessment must be well- structured, and continuously implemented as part of the classroom activities. Since assessment is one of the strong tools for assessing pupils' strengths and weaknesses, assessment should concentrate on a broad range of mathematical tasks and skills (Cheah, 2010; Ministry of Education Malaysia, 2003).

1.2 Research Background

Geometrical measurement has a unique and special place in almost all mathematics curriculum. Considering its vital role in mathematics, science and our life, pupils should thoroughly understand not only how to solve geometrical measurement problems numerically based on formula but also understand the underlying concept of geometrical measurement (Tan Sisman & Aksu, 2016). In order for pupils to understand the conceptual basis of geometrical measurement, pupils need to attain good geometrical measurement skills as geometrical measurement skills integrate both spatial and numerical skills (Vasilyeva et al., 2009a). Several past studies have shown that spatial and numerical skills support pupils' learning in various topics especially geometrical measurement (Clements & Battista, 1992; Tůmová & Vondrová, 2017). Mathematics researchers and educators have indicated that pupils' inflexibility in managing geometrical measurement problems may result from the curriculum and the assessment of school mathematics (Huang & Witz, 2011). Besides, there is limited number of assessment instrument that are developed to assess pupils in geometrical measurement skills based on spatial skills and also numerical skills (Vasilyeva et al., 2009b). Due to the importance of geometrical measurement skills in determining the success of geometrical measurement, this study aims to develop a new assessment instrument that is theoretically grounded to determine pupils' level of geometrical measurement skills in geometrical measurement and identify pupils error patterns in solving the geometrical measurement skills instrument in geometrical measurement.

1.2.1 Assessment and Assessment in Geometrical Measurement

As demonstrated by the Malaysian Ministry of Education Circular Letter [Ref.no: KPM.100-1/7/2 Jld.6(17)] (2018), the education system has been reformed with the abolition of middle and end-of-year examinations of lower primary school pupils, which entered into force in 2019. This approach has been taken to assess pupils' development in a holistic way and, at the same time, to allow teachers to concentrate more on learning and inculcating value to pupils. Also, School-Based Assessment in Malaysia is not a new initiative but has been introduced since 2011 and 2012 to Year One primary school pupils and Form One secondary school students respectively (Malaysian Examinations Syndicate, 2014). Although the formative School-Based Assessment is very useful in determining pupils' achievement and identifying pupils' difficulties in learning, it imposes pressure on teachers to select and create appropriate assessments for measuring specific skills (Nor Hasnida, 2016a; Ong, 2010). Therefore, developing meaningful assessment tools are essential not only to assess students' skills and abilities, but also to determine their difficulties and weaknesses.

Geometrical measurement is a topic usually studied by pupils between 8 to 12 years of age. When studying geometrical measurement, pupils extend their knowledge of geometric shapes and their attributes to measurement (Crites et al., 2018). Geometrical measurement can be defined as the measurement of perimeter, area and volume in one, two and three dimensions respectively and it covers most of the core components in mathematics (Kim et al., 2017). For example, the components of geometrical measurement form the basis of number lines, arrays in multiplication, fractions, graphics and other topics. In addition, geometrical measurement also form the basis of physics, chemistry, biology, geology and geography, and architecture and art (Fuson et al., 2010). Therefore, geometrical measurement is one of the important topics in school mathematics.

According to Outhred et al. (2003), pupils have been studying geometrical measurement since the first years of school and are usually introduced as a measurement comparison between objects, (i.e. shorter or longer than) before pupils are introduced to learn more complex geometrical measurement concepts in subsequent years. The first concepts to be introduced in geometrical measurement are length and perimeter measurement, as the concepts are essential to ensure that pupils succeed in area and volume measurement (Outhred et al., 2003). These early concepts of measurement include understanding the spatial attributes and the use of informal units to measure and compare. Such concepts are important because they provide the basis for the estimation and geometrical measurement skills that will be learned in late primary and early secondary schools.

Geometrical measurement is considered as a one of the crucial topics in Mathematics as it is being assessed in the international large-scale assessment such as the Trends in International Mathematics and Science Study (TIMSS). Chog et al. (2018) in their study stated that the content domain for geometrical measurement in Grade 4 and Grade 8 Mathematics TIMSS 2015 is 35% and 30% respectively. For these reasons, greater focus should be put on pupils, beginning from primary school to ensure that geometrical measurement skills in geometrical measurement are not being neglect, knowing its importance in mathematical learning.

In order for pupils to excel and succeed in geometrical measurement, pupils need to understand the underlying concepts and not only understand the definition of geometrical measurement that are based solely on formula (Machaba, 2016). Besides, most pupils who correctly apply the formulas for perimeter, area and volume measurement do not even understand how the formulas work. One of the main reasons for this issue is the lack of assessment of the skills associated with conceptual understanding in this particular topic (Battista, 2003a). To overcome this issue, specific mathematical knowledge and skills that are related to the topic must be accurately assessed (Clements et al., 2008). Such attention to the conceptual understanding of geometrical measurement generates a need for a new approach to the development of the assessment instrument.

1.2.2 Geometrical Measurement in Malaysia Context

In Malaysia, pupils are introduced and exposed to geometrical measurement since at the pre-school level of education (Noraini, 2009). In Malaysia primary school Mathematics curriculum, pupils begin to study geometrical measurement beginning from Year One until Year Six of their education. In Year One, pupils are introduced to compare the length of two or more objects (e.g., longer or shorter than) and identifying two-dimensional and three-dimensional basic shapes. Pupils are then continued to study the characteristic of two-dimensional and three-dimensional basic shapes in Year Two followed by recognizing and identifying the characteristic of different shapes such as prisms, semicircle and regular polygons in Year Three. In Year Four, pupils are introduced to determine the perimeter and area of two-dimensional shapes and the volume of three-dimensional shapes. Pupils are then studied the perimeter and area of two-dimensional composite shapes followed by the volume of three-dimensional composite shapes. In the last year of the primary school i.e., Year Six, pupils need to solve the problems situation involving the perimeter and area of two-dimensional composite shapes. In addition, pupils need to solve problems situation involving the volume of three-dimensional composite shapes (Ministry of Education Malaysia, 2003).

At the end of six years primary education, pupils will sit for Primary School Evaluation Test (UPSR) to determine their achievement at the primary level (Ong, 2010). Mathematics is one of the subjects to be tested in UPSR and geometrical measurement contributed approximately 10 percent of the overall marks from the analyses of the UPSR questions for 2016, 2017 and 2018. In fact, the topic of geometrical measurement will also be tested in public examination at the secondary level, namely Form three Assessment (PT3) and Malaysian Certificates of Education (SPM). This shows that Malaysia's curriculum places great emphasis on learning geometrical measurement as this subject is studied every year from pre-school to secondary school and also being tested in the public examinations. Therefore, suitable educational methods and activities such as the development of effective assessment instruments must be enhanced in order to improve geometrical measurement understanding especially at the primary level (Jones & Tzekaki, 2016). This is because, according to Carroll (1998), pupils who have gained a clear understanding of geometrical measurement during primary education would do better to solve geometrical measurement problems in their secondary education.

1.2.3 The Importance of Geometrical Measurement Skills in Primary School

Geometrical measurement skills have a long and significant position in mathematics due to the strong demand in numerous professions and workplaces (Smith et al., 2011). Thus, it is not surprising that geometrical measurement skills have been introduced since preschool and have developed and extended at both primary and secondary levels. Geometrical measurement skills at the primary level typically focus on geometrical measurement i.e. the measurement of perimeter, area and volume (Steele, 2006). However, primary school pupils often do not have a good understanding of geometrical measurement due to the lack of geometrical measurement skills (Tůmová & Vondrová, 2017). Geometrical measurement skills play an important role in helping primary-level pupils gain conceptual understanding of geometrical measurement as geometrical measurement skills combine spatial skills that help them make sense of objects in the world around them and connect them to numerical skills to better understand the significance of geometrical measurement formula (Barrett et al., 2012).

In order for pupils to understand and solve geometrical measurement problems, pupils need to acquire good geometrical measurement skills because, according to Tan Sisman and Aksu (2016) pupils need to understand not only how to measure but also what it means to measure. In addition, Casey et al. (2011) stated in their study that, in order to grasp good geometrical measurement skills, pupils need to gain understanding of the underlying spatial definition of measurement as well as numerical and procedural competence. . Therefore, the assessment of measurement must take into account the pupils' intuitive spatial understanding and help them link this understanding with numbers (Clements & Battista, 2001). Furthermore, geometrical measurement has long been considered by researchers to integrate both numerical and spatial skills (Battista, 2003b; Casey et al., 2011; Miller, 1989; Vasilyeva et al., 2009b).

Although studies in the field of measurement have found that excellent geometrical measurement skills depend on two constructs which are spatial skills and numerical skills, the connection between the constructs and the level of achievement of the geometrical measurement skills has barely been explored (Casey et al., 2011). Therefore, in this study, the integration of spatial skills and numerical skills are involved in developing instrument to assess geometrical measurement skills in geometrical measurement in order to grasp pupils' understanding.

1.2.4 Assessment in Geometrical Measurement Skills

Geometrical measurement skills are one of the crucial skills that need to be measured as it is important in various subjects such as mathematics, science and vocational education (Smith et al., 2011; Vasilyeva et al., 2009b). Besides, geometrical measurement skills are an essential part of the mathematics curriculum (Smith et al., 2011) and is highly practical and useful compared to most other skills in mathematics (Grootenboer & Sullivan, 2013). Furthermore, geometrical measurement skills contain important practical skills that are needed in everyday life, Van den Heuvel-Panhuizen & Buijs (2004) making it special in mathematics and other topics (Baroody et al., 1998). This can be proved by most psychologists and educators who stressed the importance of measurement as a unique role in understanding mathematics and science, (Clements et al., 2013; Clements & Bright, 2003; Lehrer et al., 2003; Miller, 1989; Vasilyeva et al., 2009a), where measurement can transform the psychological and physical properties of the world into numbers so as to enable people to mathematically understand them (Vasilyeva et al., 2009a).

Despite the importance of geometrical measurement skills in various fields, there are limitations and difficulties in the learning of geometrical measurement skills. According to Kloosterman et al. (2004), a number of research findings have shown that pupils have problems in understanding the measurement concepts and skills. This is due to the lack of conceptual understanding of the measurement concepts (Vasilyeva et al., 2009b). Although there is a loophole for pupils to learn geometrical measurement skills, research in geometrical measurement skills is less robust and less comprehensive than research in other fields. Besides, the research on geometrical measurement skills has not been thoroughly integrated with the improvement of assessment tools. Thus, there is a need to develop a new assessment tool, such as a new approach to the development of an assessment instrument, especially in geometrical measurement, as geometrical measurement skills can provide a strong basis for conceptual support for geometrical measurement (Barrett et al., 2012)

1.2.5 Error Patterns in Geometrical Measurement

Pupils' errors and misconceptions in mathematics are considered a valuable tool for disclosing concepts, ways of thinking and difficulties in learning (Ashlock, 2010; Greeno et al., 1996). An error is the wrong responses to a problem and the incomplete knowledge of fundamental facts, concepts and skills (Hadjidemetriou & Williams, 2002). A misconception is a pupil conception that generates a systemic error pattern (Smith et al., 1994). Misconceptions about what has been learned are revealed through error patterns (Ashlock, 2010). Besides, errors and misconceptions can reveal the pupils' thinking on internalizing concepts and skills (Radatz, 1980; Ryan & Williams, 2007).

Vasilyeva et al. (2009a) revealed in their study that there are three types of error patterns for spatial skills item involving geometrical measurement namely, the inverse rule problem, which involves coordinating information about unit size and number of units (Lehrer, 2003; Wilson & Rowland, 1993), estimation problems in which it can be solved either by comparing the target object with the other known objects or by systematically generating a measurement unit and iterating units and lastly the volume grid problems where pupils need to count units by visualizing an array within a coordinate-like system (including the invisible units). Furthermore, the error patterns for formula-based items mentioned in this study are errors in choosing appropriate formula, using non-existent formula, error in carrying out calculation and both error in choosing appropriate formula and carrying out calculation. For more complicated problems that involve formula manipulation, the error pupils tend to do is performed a single step of a multi-step solution.

Furthermore, Tan Sisman and Aksu (2016) pointed out the common errors and misconceptions in perimeter, area and volume respectively. The common errors and misconceptions stated in this study are (a) perimeter is constant, when the shape is rearranged; (b) counting the square units or dots for perimeter; (c) using units of area/volume measurement for perimeter; (d) using the area formula for perimeter; and (e) perimeter equals to the total of two side lengths. For area measurement the common errors and misconceptions are a) believing that area is not constant, under partitioning; (b) counting the lines around a shape for area; (c) point-counting for area; (d) confusing area with perimeter; (e) using the perimeter formula for area; (f) area equals to length plus width; (g) using units of length/volume measurement; (h) using the volume formula for surface area; (i) surface area equals to length plus width plus height; (j) confusing surface area with volume; and (k) believing that a shape has more than one surface areas. Lastly, for volume measurement, the common errors and misconceptions are a) counting the square units, (b) counting faces of unit cubes, (c) counting only visible unit cubes, (d) double counting unit cubes, (e) counting the faces of unit cubes given in the picture and doubling that number, (f) counting the faces of unit cubes given in the picture and multiplying that number with 3 because a prism has three dimensions, (g) volume equals to length + width + height; (h) volume equals to length × width and (j) volume equals to length × width + height, and (k) using units of length/area measurement.

1.2.6 SOLO Taxonomy in Assessment and Error Analysis

SOLO Taxonomy is a powerful assessment tool not only for the development of assessment instruments, but also for the scoring of instruments that allow the crediting of partial knowledge and can also be used as a meaningful reporting tool for teachers and pupils. Thus, it is not surprising that SOLO Taxonomy has been widely used in various school subjects such as geography, science, economics, chemistry, computer science and mathematics (Hattie & Brown, 2004). Besides, SOLO Taxonomy was used to explore the structure of the pupil's problem-solving abilities, mathematical thinking skills and understanding of mathematical concepts over a broad educational range from primary to secondary levels (Lim & Noraini, 2006).

To design and develop meaningful assessment instruments, the combination of SOLO Taxonomy and the idea of super item test format has been used and this combination has successfully indicated the cognitive ability at a certain level according to the SOLO Taxonomy level of understanding (Mukuka et al., 2020). This combination involves constructing a series of 4 items that are related to a single text or prompt that is the stem of the questions, with each item measuring one level of the

SOLO Taxonomy (unistructural, multistructural, relational and extended abstract) (Hattie & Brown, 2004). By applying SOLO Taxonomy in the super item format, the items would be on a scale of increasing difficulty or complexity. Thus, this combination makes it possible to assess pupils' geometrical measurement skills in geometrical measurement especially identifying in broad terms the level at which a pupil is currently operating.

Apart from being used in development assessment instruments, SOLO Taxonomy has also been used to analyze errors (Christinove & Mampouw, 2019; Lim & Wun, 2012). Error analysis using SOLO Taxonomy can provide information on pupils' errors more precisely based on the level of SOLO Taxonomy. Besides, errors could be detected at each level from the very beginning, making it easier for teachers and pupils to improve their teaching and learning. Thus, in this study, pupils' error patterns in solving geometrical measurement skills instrument are analyzed based on SOLO Taxonomy to determine the specific errors patterns in each SOLO Taxonomy level of understanding.

1.3 Problem Statement

Geometrical measurement (perimeter, area and volume measurement) is one of the most difficult fields of primary school mathematics (Battista, 2003a; Vasilyeva et al., 2009b). Besides, several studies on measurement have indicated that pupils have poor understanding in geometrical measurement (Browning et al., 2014; Kim & Oláh, 2019; Tan Sisman & Aksu, 2016). This can be shown by the performance of pupils in international assessment such as Trends in International Mathematics and Science Study (TIMSS) where geometrical measurement is regularly found to be an area of weaknesses (Crites et al., 2018; Mullis et al., 2004). The reason for this is that most pupils have learned how to calculate and solve geometrical measurement problems by memorizing and applying formulas using step-by-step procedures without addressing the underlying concepts of geometrical measurement in their primary education (Crites et al., 2018; Smith et al., 2016). In fact, pupils who learn by memorizing formulas appear to forget information that has been memorised, confused, and unable to relate that information to different situations (Mohd Faizal & Leow, 2017). This can actually reduce pupils' interest in learning geometrical measurement.

The achievement of Malaysian primary school pupils in geometrical measurement is still insufficient. This statement can be proved by the analysis of the Malaysia Primary School Evaluation Test (UPSR) answer quality, issued by the examination syndicate, geometrical measurement problems still exist among pupils in which pupils still do not comprehend the idea of geometrical measurement due to the lack of conceptual understanding and do not know the formulas that need to be used to solve the problems in geometrical measurement (Malaysian Examination Syndicate, 2010, 2012, 2013, 2014, 2017). Besides that, there is evidence showing that many Malaysian secondary students still lacking geometrical measurement knowledge although it has been taught every year starting from the first year of primary school. This is proven by the result of the 2015 TIMSS where the rank of Malaysia in geometrical measurement content domain remains unchanged and still below the average score and is categorized as a low international benchmark (Chog et al., 2018). This study therefore selects primary school pupils, i.e., the Year Five, to gain deeper knowledge and input from the pupils as they studied the basic geometrical measurement in Year 4. In addition to this instrument, the emphasis is on the composite figure that is learned by Year Five pupils, considering the composite figure items were mostly evaluated in UPSR and TIMSS. Due to time, cost and language constraint, this study is done to only National Primary School.

According to Battista (2003a) most of the pupils did not understand how the geometrical measurement formulas work even though they could apply the formulas correctly. One of the main reasons for this issue is the lack of assessment of the skills associated with conceptual understanding in geometrical measurement (Crites et al., 2018; Hannighofer et al., 2011; Vasilyeva et al., 2009b). Besides, Battista (2012), Battista, (2007a), Huang and Witz (2012) mentioned in their study that many problems in geometrical measurement occurred due to a missing link between spatial and numerical skills where pupils did not understand the underlying structure behind geometrical measurement formulas, e.g. area = length x width. Therefore, it is essential to develop an assessment tool that covers a wide variety of geometrical measurement skills that involves the specific types of constructs i.e., spatial and numerical skills to better inform the teaching and learning in geometrical measurement.

Even though the researchers in the measurement field have hypothesized that geometrical measurement skills rely on both spatial and numerical skills, the relationship between these cognitive skills and geometrical measurement skills has not been assessed directly. In fact, hardly any empirical research has been conducted to explore the factors affecting geometrical measurement skills (Casey et al., 2011). Besides, Battista (2012), Clements and Battista (2001) and Crites et al. (2018) mentioned in their study that the typical assessment and instruction method has always been formula-centred, which could potentially hinder the development of geometrical measurement concepts and skills. Moreover, Hwang et al. (2019) stated in their study that there are lack of studies done to determine pupils' level of geometrical measurement skills and their weaknesses in geometrical measurement and this issue caused problems for teachers to determine the level and weaknesses of pupils. Therefore, designing an assessment tool that can provide an adequate opportunity for pupils to gain a conceptual understanding of geometrical measurement that goes beyond rote memorization is required. Besides, the instrument might provide meaningful insights for teachers where teacher could get deeper into what the pupils understand.

Geometrical measurement skills in geometrical measurement can be assessed by paper-and-pencil instrument such as the one developed by Tůmová and Vondrová (2017) which consist of 28 test items assessing spatial skills and 11 items assessing numerical skills. However, the test instrument used in the study was developed by modifying several existing tests to assess spatial skills in geometrical measurement such as Amthauer I-S-T universal intelligence tests (2001), Differential Aptitude Test: Space Relations (2009) and other spatial ability tests that are available on-line. In fact, the test used was not based on the specific spatial skills constructs (e.g., spatial visualization, spatial structuring or spatial orientation) that are required to measure geometrical measurement. Based on the literature review, two sub-constructs of spatial skills are required to assess geometrical measurement at the primary level, i.e. spatial visualisation (Battista, 1999a; Ben-Haim et al., 1985; Lehrer, 2003; Revina et al., 2011; Tan Sisman & Aksu, 2016) and spatial structuring (Battista & Clements, 1998; Battista et al., 2003; Battista et al., 2017; Lehrer, 2003; Newcombe et al., 2019; Pittalis & Christou, 2010; Revina et al., 2011; Tan Sisman & Aksu, 2016). Moreover, items that are developed to assess pupils' numerical skills in the study only used non-routine tasks that requires complex use of formulas without covering a wide continuum of complexity. By using only non-routine and complex items, it is impossible to determine the level of pupils' understanding and also the errors done by pupils at each level. According to Vasilyeva et al. (2009a), items with different level of complexity allow to distinguish pupils' level of geometrical measurement skills and concepts. Therefore, this study aims to develop an assessment instrument targeted at specific skills that are directly related to geometrical measurement and also with varying difficulties, so that more details of how pupils develop their knowledge of geometrical measurement can be explored.

Although there is a study conducted by Vasilyeva et al. (2009a) to develop geometrical measurement skills instrument in geometrical measurement with different levels of difficulty, all the items were developed in the multiple-choice format. According to Norjoharuddeen and Noraini (2010), the multiple-choice test format is restricted in forcing students to respond by choosing only the justification provided in the choices. Thus, the responses given by pupils did not provide valuable insights to determine the depth of pupils' understanding in geometrical measurement. Thus, this study employed a super item format i.e., the open-ended format based on the SOLO Taxonomy level of understanding (unistructural, multistructural, relational and extended abstract) in order to monitor the growth of pupils' geometrical measurement skills in solving geometrical measurement problems. Besides, from the review of literature, none of the existing assessment instruments assessing pupils' geometrical measurement skills in geometrical measurement used SOLO Taxonomy as the framework to the development of the test instrument.

Several studies have been conducted to develop assessment instrument to assess geometrical measurement skills in geometrical measurement (Hannighofer et al., 2011; Tůmová & Vondrová, 2017; Vasilyeva et al., 2009b). However, it is found that the instrument development and validation approaches of the studies are based on the Classical Test Theory (CTT) e.g., the use of the Confirmatory Factor Analysis

(CFA). Besides, there is a study that relies on only the calculation of success rates. According to Mohd Zaidi et al. (2010) good assessment instrument relies on the correct method of data analysis. In order to obtain meaningful analysis that provide different perspective to the same data, the Rasch analysis can be used. Through Rasch analysis, more accurate and meaningful inferences such as determining the relationship between the pupils' ability and item difficulty level, identifies poorly functioning items as well as unexpected responses can be made on the data that gathered, especially for activities of assessment for learning (Sumintono, 2018). Thus, in this study, the Rasch Partial Credit Model are used to determine the construct validity of the assessment instrument and to classify pupils' geometrical measurement skills level based on the SOLO Taxonomy level of understanding. According to Lim and Wun (2020), by applying Rasch analysis and SOLO Taxonomy, the quality of the test items can be determined in terms of the psychometric properties as well as the classification of the item hierarchy based on SOLO Taxonomy can be examined.

Studies in measurement area have shown that pupils have difficulties in solving geometrical measurement (Tan Sisman & Aksu, 2016). Thus, identifying error patterns is considered to be a valuable technique for disclosing concepts, ways of thinking and learning difficulties (Ashlock, 2010; Greeno et al., 1996). Error patterns reveal misconceptions that have been learned (Ashlock, 2010). However, there has been lack of study done to identify the errors done by pupils in geometrical measurement (Tan Sisman & Aksu, 2016). Besides, several studies on the determination of pupils' errors and misconceptions in geometrical measurement have mainly been studied and addressed in general, without discussing specific errors according to the level of pupils' understanding (Tan Sisman & Aksu, 2016; Vasilyeva et al., 2009a). Therefore, this study aims to identify specific error patterns according to the level of pupils' understanding, so that teachers can gain useful insight into planning strategies and remedial practices to improve student achievement in geometrical measurement. According to Christinove and Mampouw (2019), Lipianto and Budiarto (2013) and Yarman et al. (2020), by using SOLO Taxonomy, the error patterns done by pupils can be classified systematically according to the SOLO Taxonomy level of understanding i.e. unistructural, multistructural, relational and extended abstract. Thus, this study aims to identify error patterns in geometrical measurement skills by applying the SOLO Taxonomy.

The reports of large-scale international studies show a significant difference in gender among primary school pupils in geometrical measurement skills (Mullis et al., 2000). Gender differences in geometrical measurement skills, particularly spatial skills, have been widely studied. However, there has been little research into whether the relationship between spatial skills and numerical skills differs between males and females. Furthermore, gender differences are evident in only certain spatial constructs, such as spatial orientation and mental rotation, but not in others, such as spatial constructs i.e., the spatial visualization and spatial structuring (Harris et al., 2021). Besides, Hutchison et al. (2019) stated in their study that there are different conclusions regarding gender differences involving spatial and numerical skills, some of which have seen a gender gap favouring boys, others have seen an advantage favouring girls, and some have seen no gap at all. Due to the conflict of opinion about gender difference in spatial and numerical skills, therefore, this study will examine the gender differences not only on geometrical measurement skills, but also numerical skills and spatial skills. In addition, there are no research examining gender differences in geometrical measurement skills explicitly for primary pupils in geometrical measurement.

1.4 Research Objectives

Based on the statement of problem, the objectives of this study are:

1. To develop Geometrical Measurement Skills Instrument (GMSI) to assess Year Five National School pupils in geometrical measurement.
2. To profile the items in Geometrical Measurement Skills Instrument based on item difficulty and pupils' ability according to spatial skills, numerical skills, content domain and SOLO Taxonomy level of understanding.
3. To examine gender differences among Year Five National School pupils in geometrical measurement skills in geometrical measurement
4. To analyse error patterns of Year Five National School pupils in GMSI.

1.5 Research Questions

The result of this study is hoped to answer the following questions.

1. To what extent is the GMSI in geometrical measurement valid in terms of:
   a) content validity?
   b) the descriptors of the assessment framework?
   c) construct validity and reliability in terms of:
      i) item dimensionality?
      ii) item dependency?
      iii) item fit?
      iv) item polarity?
      v) person and item reliability and separation indices?

vi) item difficulty and pupils' ability?

vii) Differential Item Functioning?

2. What is the profile of the items in Geometrical Measurement Skills Instrument in terms of:

   a) items difficulty according to spatial skills, numerical skills, content domain and SOLO Taxonomy level of understanding?

   b) pupils' ability according to SOLO Taxonomy level of understanding?

3. Is there a significant difference between male and female Year Five National School pupils in:

   a) geometrical measurement skills?

   b) spatial skills and numerical skills?

4. What are the error patterns of Year Five National School pupils in:

   a) unistructural level items of GMSI in geometrical measurement?

   b) multistructural level items of GMSI in geometrical measurement?

   c) relational level items of GMSI in geometrical measurement?

   d) extended abstract level items of GMSI in geometrical measurement?

1.6 Significance of the Study

Assessment is one of the important elements in education. In Malaysia, the concept of school-based assessment has been introduced to the classroom assessment in order to improve the current school examination practice (Malaysian Examinations Syndicate, 2014). Thus the, the key purpose of assessment is supposed to guide pupils in learning. Assessment must therefore play a significant role in engaging pupils to develop their own thinking and understanding of a topic or subject. In this study, a new approach of developing assessment instrument is explored to ensure that pupils have the opportunity to understand and go deeper into learning the topic or subject they are involved in. The assessment instrument developed in this study is based on an assessment framework that uses SOLO Taxonomy to focus on increasing level of understanding, with the benefit of classifying items based on surface and deep level of understanding. Furthermore, the newly developed instrument facilitates the determination of pupil levels and therefore helps guide pupils in their learning process. Thus, the findings of this study provide an alternative assessment tool in the current education system.

At the same time, the result of this study might provide evidence on the significance of the developed assessment framework i.e., based on the SOLO Taxonomy level of understanding in order to develop instrument to assess pupils' geometrical measurement skills in the primary. Besides that, the instrument of the study might also be used as a diagnostic assessment tool to evaluate pupils' strengths and weaknesses in geometrical measurement skills and also their conceptual understanding in geometrical measurement. Furthermore, the valid framework and instrument can be used as a template and guidance for teachers and pupils in various geometric topics. It could be a suitable platform to refer on a wide range of structures in learning mathematics at primary school level.

From the result of this study, teachers are provided with a guideline to identify the level and the process of their pupils' ability in solving geometrical measurement skills questions in the subtopic geometrical measurement. Teachers will be able to assess pupils' thinking and understanding in geometrical measurement due to the result from the findings offer a practical tool for designing and assessing. This is because different types of assessment allow teachers to observe different dimensions of pupils to obtain a global picture of their knowledge and skills.

In this study, besides examining the relations between key cognitive skills and geometrical measurement skills achievement, this instrument could also be used to investigate the nature of gender differences in geometrical measurement skills. The difference between numerical and spatial skills may be highly relevant for gender differences because one of the main cognitive gender differences in literature is male dominance over spatial skills (Halpern, 2000; Johnson & Meade, 1987b; Voyer et al., 1995). Therefore, by defining different elements of geometrical measurement skills, researchers can understand the type of difficulties faced by each gender group and, at the same time, support and direct educators to identify strategies and techniques used to improve the level of geometrical measurement skills among pupils. Besides that, the research could also be a reference for other researchers who would like to further their research in other fields of study. Perhaps and even more significant is that there were very few researches conducted concerning the assessment of geometrical measurement that makes this study essential for mathematics learning.

Geometrical measurement or measurement of space was seen as an integration of numerical and spatial skills (Miller, 1989; Vasilyeva et al., 2009a; Wilson & Rowland, 1993). From previous studies, most of the studies conducted focused only on specific geometrical measurement skills such as identifying pupils' problems in area or perimeter (e.g., Hiebert, 1984; Kamii, 1995; Nitabach & Lehrer, 1996; Outhred & Mitchelmore, 2000) without utilising numerical and spatial elements of measurement. Therefore, by designing an instrument that requires different types of constructs, researchers will be able to gain a larger picture of the geometrical measurement skills and recognize which measurement construct generates the most difficulty for pupils. Besides, by identifying the error patterns made by pupils in GMSI, pupils, teachers and also researchers could obtain the information on the specific errors at the specific level of understanding.

1.7 Limitation of the Study

Limitations are important to acknowledge in any research study (Connelly, 2013). Therefore, this study had a number of limitations to be considered. The limitations are a) the sample used in this study include only primary school pupils, b) population in this study consist of only Year 5 pupils, c) the schools involve in this study is National Primary School d) the sampling area includes only selected schools from each district of the Penang state and e) the topic studied in this research only covers geometrical measurement (perimeter, area and volume). Each of these limitations is explained below.

In this study, the population covers only Year 5 primary school’s pupils and not including year 4 pupils. This is because, in the curriculum and assessment standard, the topic that is studied in this study are being taught to Year 5 pupils. Moreover, the instrument developed in this study assess geometrical measurement that involved items containing composite figure and only be learnt by Year Five pupils. Besides that, due to cost, time, language and Covid-19 pandemic constraint the study will only be done to Year 5 pupils in National Primary School.

In this study, the sampling area covers the entire Penang state. However, due to financial, time and Covid-19 pandemic constraints, the sample of this study includes only 500 pupils and the sampling area is limited to several schools in five districts of Penang. Apart from this, this study is limited to the topic of geometrical measurement.