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A Comparative Study on Statistics Competency Level Using TIMSS Data: Are We Doing Enough?

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This article seeks to present findings from the analysis of these TIMSS reports and determine if the present Malaysian statistics curriculum has produced students that achieved a level comparable to some of the advanced and developing countries. The significance of making this comparison lies in its forecasting value as basic statistical foundation mastered in the respondents' formative years can have great impact on their later performance in higher statistics courses especially for those who will enter the university. Results of the authors' analysis placed Malaysia in the 'Intermediate' band i.e. an average achievement band together with United States, Australia and Russian Federation but fell behind Singapore. The article closes with some recommendations on how educators can improve the teaching and learning of statistics in secondary and higher education.

Key words: TIMSS, competency in statistics, curriculum, quantitative skill.

Introduction

Statistics education in Malaysia starts at the early age of 9. Students are taught statistics throughout their primary and secondary education until the age of 17 after which they are given a choice of taking up an advanced statistics paper. The topics in the primary years cover data handling, presentation of data using table, picture or chart and conclude with an introduction to the concept of average. At the secondary level, students are exposed to simple ideas about frequency using tally chart and frequency table. Data collection methods are also discussed while at the end of their secondary schooling, students are exposed to simple ideas concerning probability and statistics. When students reach A-Level Mathematics, they are taught more advanced concepts in data description, probability and statistics. Additional topics like discrete and continuous probability distributions, sampling and estimation (point and interval), correlation and regression in addition to time series and index numbers are also taught in class (Ministry of Education Malaysia, 2004, 2006). The Singaporean syllabus begins with the teaching of statistics at Primary 1, covering data handling and representation using picture graph, bar graphs, tables and line graph. In Primary 5, students begin to learn about the average of a data set while the pie chart is covered in Primary 6. When they are in the secondary schools, advanced concepts of data handling, probability and statistics are covered with topics like measures of centrality and measures of dispersion. A-level students taking mathematics papers are required to learn more challenging concepts of probability in addition to new topics like discrete and continuous probability distributions, sampling and estimation (point and interval) and hypothesis testing for population mean and proportion (Ministry of Education Singapore, 2006). Basically the statistics syllabi in both countries share a lot of similarities where once both countries were under the same educational system.

Why do students and even mathematics teachers find the topics in probability to be comparatively difficult to handle and sometimes even baffling? Probability can be quite deceptive at times. Take for example, in algebra A=2, B=5 therefore A+B=7. In probability on the other hand, P(A)=0.2, P(B)=0.5 but P(A U B) sometimes is equal to 0.7, but sometimes it is not depending on the assumption of intersection! In geometry and algebra we can use deductive reasoning to prove, but in probability, inductive reasoning is the norm and resorting to this type of reasoning to prove is not possible. Students find it confusing and bewildering trying to accommodate probabilistic ideas into the already-formed mathematics cognitive structures. Learning statistics is not only about acquiring facts but developing statistical reasoning and thinking as well. How well are we doing in this area is a question which begs to be answered. Attempts to find the answer leads us directly to the problem of assessing statistical reasoning and thinking. Understandably, assessing the status of a student's statistical thinking is important, for then only can we detect faulty reasoning. The TIMSS employs well-developed and reliable assessment instruments that can provide vital information concerning the curriculum, pedagogy, academic attributes and most importantly the understanding of the students involved. In the section below, our primary focus will be some indicators of Malaysian students' performance in statistics as compared to a few selected countries.

An Analysis of the Statistical Foundation of Eighth Grade Students

The Trends in International Mathematics and Science Study (TIMSS) is an international effort jointly supported by national research institutions and government research agencies of participating countries. It is under the supervision of the International Association for the Evaluation of Educational Achievement (IEA). IEA's main function is to develop and implement at the international level the TIMSS study on a four year basis. It seeks to "measure over time the mathematics and science knowledge and skills of fourth and eighth-graders. TIMSS is designed to align broadly with mathematics and science curricula in the participating countries" (Gonzales et al 2008).

The TIMSS studies are cross-national in nature. They compare the performances of fourth grade and eighth grade students in Mathematics and Science assessments. The test items measure the knowledge and skills of students over time. The items in the eighth grade mathematics assessment include 4 main areas, namely Number, Algebra, Geometry as well as Data and chance.

The sampling for TIMSS involves obtaining a minimum size of 4000 participants from each country. Data collection is carried out using mathematics and science achievement tests. Associated questionnaires are also administered to students and teachers. Data analysis involves both descriptive and inferential statistics where statistical tests, confidence interval and effect sizes are reported (Gonzales et al 2008).

To give meaning to the score, TIMSS uses scale anchoring at 4 points to translate what each student's standardized score means relative to its position along the scale. The four cut-points are given in Table 1 below. These cut-points describe in qualitative terms what kinds of skills and knowledge students at each cut-point would need to successfully answer the mathematics items asked in the test. Take, for example, if a student scores 580, he/she is emplaced in the 'High' band and is expected to be able to apply understanding and knowledge in a variety of relatively difficult items. In the case of "Data and chance" items, the student is able to interpret data in a variety of graphs and tables as well as solve simple problems in probability. Thus with this guideline, a student's score and an average score achieved by a particular country can be compared and interpreted meaningfully and consistently across nations.

Table 1

Description of International Mathematics Benchmarks for Eighth Grade Students – Data and Chance Domain.

Advanced (625 cut-point)	*Students can organize and draw conclusions from information, make generalizations, and solve non-routine problems.* Students can derive and use data from several sources to solve multi-step problems.
High (550 cut-point)	*Students can apply their understanding and knowledge in a variety of relatively complex situations.* They can interpret data in a variety of graphs and tables and solve simple problems involving probability.
Intermediate (475 cut-point)	*Students can apply basic mathematical knowledge in straightforward situations.* They can read and interpret graphs and tables. They recognize basic notions of likelihood.
Low (400 cut-point)	*Students have some knowledge of whole numbers and decimals, operations, and basic graphs.*

SOURCE: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS), 2007.

The next section discusses the mathematics achievement of the eighth graders in the TIMSS studies of 1999, 2003 and 2007. The focus is on the content area of "Data and chance". The countries chosen for comparison here are Singapore, Malaysia, United States, Australia, Russia Federation and South Africa. The eighth grade was chosen to compare because Malaysia only took part in the eighth grade assessment. The analysis is undertaken to understand how the 8th grade students performed mathematically in 1999, 2003 and 2007. The significance of this comparison lies in its forecasting value as basic statistical foundation mastered in the respondents' formative years can have great impact on their later performance in higher statistics courses especially for those who will enter the university. A study of the participants' achievement in 1999 and later studies could in part provide a glimpse of their ability to think and reason statistically when they pursue their higher education.

Table 2

Trend of the Average Mathematics Scores of Eighth Grade Students, by Selected Country from 1999-2007

Country	1999	2003	2007
Singapore	604	605	593
Malaysia	519	508	474
United States	502	504	508
Australia	525	505	496
Russian Federation	526	508	512
South Africa	275	264	-
International Median	487	466	463

\- Not available

SOURCE: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS), 1999, 2003, 2007.

Singapore stays ahead of many countries in term of her eighth grade mathematics achievement, attaining a high average score of more than 590 over the 3 studies. Some of the consistent top performers in TIMSS are from the Asian region like Chinese Taipei, Republic of Korea, Hong Kong and Japan. Based on the International Benchmarks for Mathematics (Table 1), this average score puts Singapore in the 'High' band. It means that an average student in Singapore is able to apply understanding and knowledge to a range of relatively difficult mathematics situations. Malaysia is located in the 'Intermediate' band along with United States, Australia and the Russian Federation. This is translated to imply that an average Malaysian student can apply basic mathematical knowledge in straightforward situations. South Africa did not fare too well lying in the 'Low' band.

There is a urgency to be cognizant of the fact that in 2003 Malaysian and Singaporean average mathematics scores were 508 and 605 respectively but in 2007 Malaysian average mathematics score dropped 34 points as compared to a 12 point drop recorded by the Singaporean cohort. Why this sudden drop? This issue has been much debated over blogs, forums, newspapers and even in parliamentary sittings! Many factors have been put forth, one of which was the switch in the medium of instruction from Bahasa Melayu to English. Dr Isahak Haron's analysis published in Berita Harian online showed that only 2% of Malaysian students achieved the 'Advanced' benchmark as compared to 6% in 2003. It was 18% in the 'High' benchmark, whereas it was 30% in 2003. Malaysia had 71% of the students in the 'Intermediate" band in 2003, but dropped to 50% in 2007 (Haron, 2009). When one compare Malaysian average mathematics score with countries like Singapore, Japan, Hungary, England, Russia, United States and Serbia, it portrays an even gloomier picture for what to expect in the next TIMSS 2011. Looking on the positive side, it is a wake-up call for Malaysian mathematics educators and policy-makers to sit up and appraise our curriculum, pedagogical approaches and strategies, and put forth much needed changes in the educational system. Apart from the language issue, another possible cause for the poor mathematics achievement in 2007 is the reasoning ability of the Malaysia cohort.

TIMSS also provides an overall mathematics scale score for the content and cognitive domain at each grade level. The cognitive domains covered in the studies are reflections of the behaviours students engaged in as they solved the problems. They are organized under "Knowing", "Applying" and "Reasoning". "Knowing" and "Applying" domains basically are similar to Bloom's Cognitive Objective Taxonomy. "Reasoning" involves students having to solve non-routine problems with unfamiliar situations, complex contexts, and multi-step procedures. An analysis of each country's achievement for 2007 according to content and cognitive domains is shown below.

Table 3

Average Scores and Standard Errors for Mathematics Content and Cognitive Domain of Eighth Grade Students, by Country: 2007

		Content domain								Cognitive domain					
		Number		Algebra		Geometry		**Data and chance**		Knowing		Applying		**Reasoning**	
Country	N	Average score*	s.e.	Average score*	s.e.	Average score*	s.e.	Average score*	s.e.	Average score*	s.e.	Average score*	s.e.	Average score)	s.e.
Singapore	4599	597	3.5	579	3.7	578	3.4	574	3.9	593	3.6	581	3.4	579	4.1
Malaysia	4466	491	5.1	454	4.3	477	5.6	469	4.1	478	4.9	477	4.8	468	3.8
United States	7377	510	2.7	501	2.7	480	2.5	531	2.8	503	2.9	514	2.6	505	2.4
Austral	40	503	3.	471	3.	487	3.	525	3.	500	3.	487	3.	502	3.

ia	69		7		7		6		2		4		3		3
Russian Federation	4472	507	3.8	518	4.5	510	4.1	487	3.8	510	3.7	521	3.9	497	3.6
#Botswana	4208	366	2.9	394	2.2	325	3.2	384	2.6	351	2.6	376*	2.1	—	†

* TIMSS Scale Average is 500

— Not available.

† Not applicable.

s.e. Standard error.

Botswana was chosen to replace South Africa as South Africa was not listed in the 2007 report

SOURCE: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS), 2007.

In TIMSS 2007, 215 mathematical items were asked, out of which 117 were multiple choice questions and 98 constructed responses. Forty-one items assessed the domain on “Data and chance”. This accounted for 19% of the total items. Seventeen used multiple-choice format and the rest, constructed responses. Table 3 shows the breakdown of the average scores by content and cognitive domains. The content that was tested comprised of “Number”, “Algebra”, “Geometry” and “Data and chance” while the cognitive domains consisted of “Knowing”, “Applying” and “Reasoning”.

How ‘Data and chance’ fares in comparison to the other areas of Mathematics is particularly of interest here. The Singaporean participants led the way in all areas of assessment in this 2007 study. They scored the highest (574) in the Data and chance section although it was not their strongest. On the other hand, the United States, with an average score of 531, and Australia, with 525, did fairly well as their students actually showed a better mastery of statistics and probability relative to the other content areas. Their students’ scores were much more consistent as evident from the much smaller variance compared to Singapore and Malaysia. Given a strong basic statistics background, it would not be surprising if Singaporean, American and Australian undergraduates have fewer issues with statistical reasoning and literacy as compared to Malaysia, Russia and Botswana. Malaysia and Russia performed only moderately well.

In the cognitive domains, "Reasoning" as expected is a much more difficult skill to acquire. The average reasoning score attained by each of the countries was generally lower than that of the "Knowing" and "Applying" domains. Are educators doing enough to improve their students' reasoning power? Indicative scores from the TIMSS studies show that educators need to pay greater attention to improving their students' reasoning ability. The ability to reason is evidently a crucial skill to master and students are expected to possess adequate reasoning mastery when they enrol into the universities. Mathematical and statistical reasoning are basic prerequisites for doing well in any mathematics or statistics courses in institutions of higher learning without which rote learning will prevail.

Table 4

Average Percentage Scores of Selected "Data and Chance" Items of Eighth Grade Students by Country; 1999 and 2003

Year	International Average	Singapore	Malaysia	United States	Australia	Russian Federation	South Africa
1999							
Average	57.0	74.9	54.7	67.6	72.1	59.6	22.9
S.D.	15.3	17.3	23.9	18.5	17.7	17.5	12.0
2003							
Average	43.4	64.7	48.5	55.2	54.5	45.9	22.7
S.D.	23.8	23.8	28.5	27.2	26.1	27.4	16.5

SOURCE: International Association for the Evaluation of Educational Achievement (IEA), Trends in International Mathematics and Science Study (TIMSS), 1999, 2003

The table above looks at the average percentage scores on the "Data and chance" domain using 10 items to give us some idea of what type of statistical knowledge and skills the students had acquired after 8 years of schooling.

The average percentage score for items assessing the probability and statistics skills shows a significant drop from 1999 to 2003. The international average registers a drop of almost 14% and it reflects a lot on the direction the teaching and learning of statistics had taken. Much remains to be done. Going back to the table above, Singapore led the pack with United States and Australia doing fairly well. Malaysia like many other countries, needs to pay closer attention to the teaching of statistics which has not been a favourite subject with students in the upper secondary level due mainly to statistics anxiety. Baharun & Porter (2009) described statistics as “perhaps the most anxiety-provoking, difficult, or critical subject”. They quoted studies by Onwuegbuzie, Slate, Paterson,Watson, & Schwartz (2000), Onwuegbuzie & Wilson (2003) and Pan & Tang (2004) purported to have reported that up to 80% of the graduate students experience uncomfortable levels of anxiety in learning statistics.

What is troubling about the 2003 statistics in regards to Malaysian students is the widening gap not only in terms of the average percentage score but also the standard deviation when compared to the 1999 study. There is a widening disparity of ability between the better and weaker students in the learning of school statistics. These findings are substantive evidence for the relevant authorities to take steps in arresting the decline.

Factors affecting effective learning of statistics

One crucial factor that has been debated and argued over the years concerns how educators teach statistics to their students. Are they communicating the abstract statistical ideas well? Are they able to assist the students to resolve the conflicts inherent in understanding complex statistical concepts? Are they merely ‘feeding’ students with facts and rules? Are they providing students with enough opportunity to understand the complexities of statistics?

Good teachers make good students, so the saying goes. Unfortunately studies have shown that the quality of teaching of statistics educators in institutions of higher learning today leaves much to be desired. Introductory statistics courses all over the world are mainly taught by educators who are not trained as statisticians (Bryce 2005). This state of affairs was highlighted by Cobb way back in 1993. He stated, “The need for curricular resources in statistics is acute, arguably more acute (at the college level) than in any other subjects taught as often as statistics, surely no other subject is so often taught by faculty with so little formal training in the subject.”

In another study, Sotos, Vanhoof, Van den Noortgate and Onghena, (2007) commented, "…a large number of statistics instructors shares the misconceptions of their students, and have an even larger influence on fostering the misconceptions than the textbooks have." How then do we produce qualified tutors and lecturers to teach the subject when they come into class ill-prepared and lacking competency in the subject matter? What is worse is that they unintentionally perpetuate the statistical misconceptions they seek to avoid.

The level of statistical understanding and misconceptions of the students must be determined before effective strategies can be implemented. Without identifying the root cause of a student's failure in understanding the basics may well defeat the usage of the most sophisticated teaching technology in class. Take for example Thomson & Buckley (2007) who suggested doing item analysis of the TIMSS 2007 results to inform pedagogy because "...we assume that students' answers can be used as evidence of their understanding of mathematics concepts. For instance, items presented via a multiple choice format offer a good opportunity to evaluate students' understanding in large scale studies like TIMSS" (pg 18). An analysis of each item will provide information concerning the trend, the level of understanding, as well as misconceptions with each topic. Henceforth will it be appropriate to talk about strategies in overcoming low level understanding or misconceptions of the students.

Conclusion

Concerns voiced by statistics educators on the ability of our students to reason and think statistically must not be taken lightly. Though they have taken statistics courses they have yet to fully develop the necessary statistical reasoning and thinking skills that would later help their research activities. Student's first encounter with statistics is normally littered with misconceptions and difficulties as the concepts are, most of the time abstract and hard to grasp. What is even more challenging is that students have to make the all important connections between statistical concepts like sample and population, variability and variation, theoretical distribution and sampling distribution, Central Limit Theorem and Law of Large Numbers. Nonetheless, the present efforts still could not overcome the varied learning difficulties inherent in the intricate complexities of the statistical learning process. Statistical learning difficulties are hierarchical in nature. The origin of errors and misconceptions can be traced to the very basic level though they are in the secondary years. The TIMSS reports gave us some indication of the difficulties our students encountered in their eighth grade mathematics courses. Learning problems at this level, if left unsolved, complicate the learning of statistics in the later years. It is imperative that statistics educators be cognizant of the problems and issues facing the students if they are to be effective teachers.

Researchers have studied students' statistical knowledge structures and conceptions as well as how these concepts develop. The general consensus is that learning statistics is not a straightforward process of purely receiving knowledge from an expert but the process involves a complex web of interrelated links among other associated cognitive components. Consequently all these make statistical understanding a challenging task. One approach to meaningful acquisition of statistical knowledge is through innovative teaching and learning strategies. Roseth, Garfield and Ben-Zvi (2008) recommends collaborative teaching and cooperative learning moving away from traditional style of presentation to student-centered teaching. Student-centered methods are far more superior to traditional methods in understanding and applying the knowledge acquired (e.g. Rumsey 1998; Franklin and Garfield, 2008). The main thrust of this approach is to involve students in project work, laboratory work, grouped problem-solving and discussion activities with the intention of developing them into active and independent learners.

Learning statistics is not only about a long list of terms to memorize and complex calculations to complete. If students are periodically exposed to many of the same type of activities they invariably will develop a negative perception towards statistics. On the other hand providing more a meaningful and realistic environment for them to practice their statistical skills will make them realize the utilitarian value of statistics while at the same time increase their statistical literacy and reasoning.

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