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When You Don't have to be Sequential: A Meta-Analysis

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Abstract

Comparison approach is a cognitive process that is often used in a variety of domains specially to support effective mathematics learning. Students with low mathematical proficiency often make mistakes when solving a mathematical problem using different types of solving strategies. These mistakes can be prevented by presenting different strategies using the comparison approach in mathematics learning. If students are encouraged to compare, the similarities and differences become highlighted. This study examines the benefits of different types of comparison approaches in mathematics learning through a systematic review of research literature published between 2009 -2018, resulting in a total of 20 interventions (20 studies) that met the criteria for this study. The findings showed that students' conceptual knowledge, procedural knowledge, and procedural flexibility are related to the greater implementation of the intervention, which when used sufficiently, can improve long-term mathematics learning. This study suggests that teachers may need additional support in preparing mathematics instruction using the comparison approach and that knowing the benefits of different types of comparisons in mathematics learning may persuade and help them to decide what to compare and when to use comparisons.

Keywords: Comparison Approach, Mathematics Instruction, Intervention, Mathematics Learning.

Introduction

Comparing approach supports learning in children and adults across a variety of domains including mathematics (Ganor-Stern & Steinhorn, 2018; Abreu_Mendoza & Arias-Trejo, 2015; Abreu-Mendoza, Soto-Alba & Arias-Trejo, 2013; Lemaire & Lechacheur, 2011). Identifying similarities and differences in multiple strategies is the basic path of flexible change in knowledge among students. However, flexible change in mathematics knowledge might be possible if students have some prior knowledge of one of the strategies in order to transfer and engage with mathematics (Star, Rittle-

Johnson, Durkin, 2016; Ziegler & Stern, 2016; Star & Rittle-Johnson, 2009; Rittle-Johnson, Star & Durkin, 2009).

Previous research has found that when students are familiar with one strategy, they can learn a new strategy via analogy to recall the familiar one (Rittle, Star & Durkin, 2009). Comparison influences classroom instruction by drawing connections through relational comparisons to improve long-term learning ability among students (Ziegler & Stern, 2016; Ziegler & Stern, 2014; Richland, Stigler & Holyoak, 2012; Clarke & Roche, 2009). In other words, students who constantly learn through comparison will experience enhanced mathematical competence in procedural knowledge, procedural flexibility and conceptual knowledge (Durkin, Star & Rittle, 2017; Ziegler & Stern, 2014, Lemaire & Lechachure, 2011; Clarke & Roche, 2009).

However, many teachers are not open to multiple solutions using the comparison approach due to over reliance on the sequential approach (Bingolbali, 2011; Rittle-Johnson, Star & Durkin, 2009). They are also unaware of effective instructional strategies (Abdul Rahman, Syed Zamri & Leong, 2018; Bingolbali, 2011; Hattikudur & Alibali, 2010). There are major challenges faced by teachers in finding appropriate instructional strategies that have a positive impact on students' learning (Fazio, DeWolf & Siegler, 2015; Ziegler & Stern, 2014). This meta-analysis attempts to determine the effective strategies in mathematics learning at kindergarten, primary school, high school and tertiary level.

Research Questions

This meta-analysis is a structured methodology aimed at synthesizing the existing studies for future improvement of the comparison approach. This study is aimed at establishing an overview of dominant types of comparison approaches at different school levels. Apart from that, this study also investigated the benefits of comparison approach in mathematics learning. Explicitly, this paper attempts to answer the research questions below:

- i. What are the dominant types of comparison approaches in mathematics learning?
- ii. What are the benefits of comparison approach in mathematics learning?

Methodology

This study used the meta-analysis design where studies related to comparison approach were analyzed systematically. In particular, meta-analysis is an analysis upon other analysis, involving the merger of research findings that are comparable and to be taken into account in determining the core effect (Cohen, Manion, & Morrison, 2011). This study followed the procedures outlined by Webster & Watson (2002) which were adapted for the purpose of choosing related articles for the study. Several databases subscribed by the University Library such as Science Direct, Wiley Online Library, Taylor & Francis Online and Web of Science were used to find the related articles. Additionally, search engines such as Google Scholar and Google Search were also used in the study. Articles related to the comparison approach in mathematics learning that were published between 2009 through 2018 were downloaded and analyzed. The search was performed using specific keywords namely: "comparison in mathematics", "comparison in mathematic strategies", "comparison in mathematics instruction", "magnitude comparison in mathematics", "numerical comparison in mathematics", and "fraction comparison strategies". The first essential

criterion for choosing an article was that it must be a study in mathematics education using the comparison approach in mathematics learning. The second criterion is that the types of samples were from different levels of education. As a result, a total of 20 studies that satisfied all the criteria were reviewed in this study, as shown in Table 1.

Table 1: List of Studies Related to Comparison Approach in Mathematics Learning

Studies	Level of Education	Sample Size	Journal
Ganor-Stern & Steinhorn (2018)	Tertiary Education	17	Acta Psychologica
Xenidou-Dervou et al. (2017)	Kindergarten and Primary School	326 (Y1) (Y2)	Learning and Instruction
Ziegler & Stern (2016)	Primary School	98 (Y6)	Learning and Instruction
Tavakoli (2016)	Primary School	113 (Y2)	Europe's Journal of Psychology
Hattikudur, Sidney, Alibali (2016)	Tertiary Education	112	Journal of Problem Solving
Ganor-Stern (2015)	Tertiary Education	62	Acta Psychologica
Fazio, DeWolf & Siegler (2015)	Tertiary Education	64	Journal of Experimental Psychology
Linsen et al. (2015)	Primary School	51 (Y4)	Learning and Instruction
Ganor-Stern & Weiss (2015)	Tertiary Education	42	Psychological Research
Abreu-Mendoza & Arias-Trejo (2015)	Special Education	48	Research in Developmental Disabilities
Ziegler & Stern (2014)	Primary School	226 (Y6)	Learning and Instruction
Abreu-Mendoza, Soto-Alba & Arias-Trejo (2013)	Kindergarten	77	Frontiers in Psychology
Sasanguie & Reynvoet (2013)	Primary School	28 (Y1) 29 (Y2) 30 (Y3)	Psychologica Belgica
Lemaire & Lecacheur (2011)	Primary School and Secondary School	39 (Y7) 36 (Y4) 31 (Y3)	Cognitive Development

Star et al. (2010)	Primary School	157 (Y5 & Y6)	Teaching Children Mathematics
De Smedt, Verschaffel & Ghesquiere (2009)	Primary School	47 (Y1)	Journal of Experimental Child Psychology
Star & Rittle-Johnson (2009)	Primary School	69 (Y5) 88 (Y6)	Journal of Experimental Child Psychology
Rittle-Johnson, Star & Durkin (2009)	Secondary School	45(Y7) 191(Y8)	Journal of Education Psychology
Star et al. (2009)	Primary School	65 (Y5) 147 (Y5 & Y6)	ZDM - The International Journal on Mathematics Education
Clarke & Roche (2009)	Primary School	323 (Y6)	Educational Studies in Mathematics

Findings and Discussion

The research findings are divided into two parts. The first part discusses the dominant types of comparison approaches in mathematics learning using the sample profile to determine the different school levels in mathematics learning that are used in the comparison task. The second part discusses the benefits of comparison approach in mathematics learning.

Types of Comparison Approaches in Mathematics Learning

RQ 1: What are the dominant types of comparison approach in Mathematics Learning?

Based on the critical analysis on the objective and the research questions, there is only one research theme from previous researches that is relevant to the analysis i.e. the types of comparison approaches followed by the different school levels and comparisons in mathematics learning.

Table 2: Research Findings Related to the Dominant Types of Comparison Approaches in Mathematics Learning

Research Themes	f	Studies (Year)
Number Comparison	7	Xenidou-Dervou et al. (2017); Tavakoli (2016); *Abreu-Mendoza & Arias-Trejo (2015); Linsen et al. (2015); Sasanguie & Reynvoet (2013); *Abreu-Mendoza, Soto-Alba & Arias-Trejo (2013); De Smedt, Verschaffel & Ghesquiere (2009)
Varieties of Strategy comparison in solving the same question	6	Hattikudur, Sidney, Alibali, 2016; Lemaire & Lecacheur (2011); Star et al. (2010); *Rittle-Johnson, Star & Durkin (2009); Star et al. (2009); Star & Rittle-Johnson (2009)
Varieties of Solution comparison in solving the same question	2	Ganor-Stern & Steinhorn (2018); Ganor-Stern (2015)
Solution Strategy comparison in a variety of mathematic operations	2	Ziegler & Stern (2016); Ziegler & Stern (2014)
Fraction comparison	2	Fazio, DeWolf & Siegler (2015); Clarke & Roche (2009)
Area comparison	2	*Abreu-Mendoza & Arias-Trejo (2015); *Abreu-Mendoza, Soto-Alba & Arias-Trejo (2013)
Types of different question comparisons with the same solution	1	*Rittle-Johnson, Star & Durkin (2009)

*Research that used two types of comparison tasks

Based on the analysis that had been carried out, it was found that most studies connected to comparative approaches are categorized under the number comparison theme. There are seven studies conducted under this theme. The number comparable theme can be classified into two parts i.e. number comparisons and comparisons of quantities of object groups. There are four studies under comparison of numbers and three studies under comparison of quantities of object groups. Additionally, there are five studies that fall under the theme of comparing various solutions strategies in the same question. Meanwhile, there are two studies each under the themes of comparison of various answer solutions in the same question, comparison of the solution strategy in distinct mathematical operations, and comparison of fractions. There is only one study under the theme of comparison of different types of questions with the same solution method. This finding reflects the broad gap that exists in the study of comparative types in mathematical learning.

The Research Sample Profile in Mathematics Learning

After analyzing the sample profile of the previous study on comparative approaches in mathematical learning, five sample categories were determined namely pre-school students, special education, primary schools, secondary schools and tertiary education.

Table 3: The Research Sample Profile

Sample	School Levels	F	Studies (Years)
Child	Pre-school	2	*Xenidou-Dervou et al. (2017); Abreu-Mendoza, Soto-Alba & Arias-Trejo (2013)
Special needs Child	Special Education	1	Abreu-Mendoza & Arias-Trejo (2015)
Child	Primary	12	*Xenidou-Dervou et al. (2017); Ziegler & Stern (2016); Tavakoli (2016); Linsen et al. (2015); Ziegler & Stern (2014); Sasanguie & Reynvoet (2013); *Lemaire & Lecacheur (2011); Star et al. (2010); De Smedt, Verschaffel & Ghesquiere (2009); Star & Rittle-Johnson (2009); Star et al. (2009); Clarke & Roche (2009)
Teenager	Secondary	2	*Lemaire & Lecacheur (2011); Rittle-Johnson, Star & Durkin (2009)
Young	Tertiary	5	Ganor-Stern & Steinhorn (2018); Hattikudur, Sidney & Alibali, 2016; Ganor-Stern & Weiss (2015); Ganor-Stern (2015); Fazio, DeWolf & Siegler (2015)

* The study has a different sample profile of education level

Based on the analysis completed, most previous studies related to the comparative approach in mathematical learning were conducted among primary school children. Ergo, there are many studies that focus on primary school children. This situation definitely reflects that there is a compelling gap in the study of comparative approaches in the context of pre-school education, special education, secondary education and tertiary education.

RQ 2: What are the benefits of comparison approach in mathematics learning?

The main research findings related to the benefit of comparison approach in mathematics according to the research objectives are as presented in Table 4.

Table 4: Research Findings Related to the Benefit of Comparison Approach in Mathematics Learning

Studies	Research Objective	Research Findings
Ganor-Stern & Steinhorn (2018)	<p>To explore the estimation skills and exact calculation task of adults with ADHD in comparison to typically developing individuals (ordinary adults).</p> <p>To explore participant's performance in both tasks using measures of accuracy and speed.</p> <p>To analyze the strategy used for the estimation task.</p>	<p>Adults with ADHD were slower in both tasks, but not less accurate compared to the control group (ordinary adults)</p> <p>They were similar in showing enhanced accuracy and speed for smaller and farther problem sizes.</p> <p>They differ in strategy execution, mainly of the approximated calculation strategy, which requires working memory resources. The participants with ADHD was weak in the calculation process in the estimation task that relied on working memory, but that did not hamper their estimation skills that are based on sense of magnitude.</p>
Xenidou-Dervou et al. (2017)	<p>To investigate the developmental roles of non-symbolic (e.g., dot arrays) and symbolic (i.e., Arabic numerals) magnitude comparison skills, play in children's mathematics learning</p>	<p>The results demonstrated that symbolic and non-symbolic comparison had different developmental trajectories; symbolic comparison underwent larger developmental improvements. Both skills were longitudinal predictors of children's future mathematical achievement above and beyond IQ and WM. Non-symbolic comparison was moderately predictive only in kindergarten. Symbolic comparison, however, was a robust and consistent predictor of future mathematics across all three years. It was a stronger predictor compared to non-symbolic, and its predictive power at the early stages was even comparable to that of IQ.</p>
Ziegler & Stern (2016)	<p>To investigate the contrasting cases under direct instruction leading to better performance in solving algebra problems than sequential learning.</p>	<p>The contrast learners clearly outperformed the sequential learners in differentiating superficially similar algebraic concepts on three follow-up measures.</p> <p>The benefits of contrasted comparison only appeared with delay.</p>

	To investigate the disadvantage of the contrast group with respect to immediate learning measures which also occur under direct instruction.	This indicates that contrast learning improves long term memorization among year six students.
Tavakoli (2016)	To investigate this relationship among second grade Iranian children using a pre-established test (known as the Numeracy Screener) to measure numerical magnitude comparison accuracy.	The results revealed that both the symbolic and non-symbolic items of the Numeracy Screener significantly correlated with arithmetic ability. However, after controlling for the effect of working memory, processing speed, and long-term memory, only the performance on symbolic items accounted for the unique variances in the children's arithmetic ability. Furthermore, while working memory uniquely contributed to arithmetic ability in one- and two-digit arithmetic problem solving, processing speed uniquely explained that only the variance in single-digit arithmetic skills and long-term memory did not contribute to any significant additional variance for one-digit or two-digit arithmetic problem solving.
Ganor-Stern (2015)	To investigate computational estimation skills of multi-digit multiplication problems using an estimation comparison task among college students.	The participants showed enhanced accuracy and speed for smaller and farther problem sizes. Moreover, approximate calculation and sense of magnitude were the strategies used to solve the task. The strategy choice was influenced by the distance between the reference number and exact answer and by the interaction of problem size and reference number size.
Fazio, DeWolf & Siegler (2015)	To examine on a trial-by-trial basis the fraction magnitude comparison strategies of adults with more and less mathematical knowledge	The findings showed that college students with high mathematical proficiency used a variety of strategies that yielded to correct performance if executed correctly. Students with less mathematical proficiency sometimes used strategies similar to those

		<p>used by the mathematically proficient students, but often used flawed strategies that yielded to inaccurate performance because of lack of conceptual understanding, rather than difficulty recalling such strategies.</p> <p>Therefore, the increases in accuracy and speed were related to differences in strategy use, strategy choice, and strategy execution.</p>
Linsen et al. (2015)	<p>To examine how numerical magnitude processing is associated with mental and algorithmic computation, and whether this association with numerical magnitude processing is different for mental versus algorithmic computation.</p> <p>To examine the possibility that associations between numerical magnitude processing and multi-digit subtraction could be explained by elementary arithmetic fact knowledge.</p>	<p>The findings showed that both calculation methods rely on numerical magnitude processing. However, mental computation is more strongly associated with numerical magnitude processing, which is considered as a basic number sense than algorithmic computation.</p> <p>Elementary arithmetic fact knowledge was also significantly correlated with both the speed and accuracy by which children solve multi-digit subtraction items.</p> <p>Results indicated that both symbolic and non-symbolic numerical magnitude comparison accuracy predicted a significant amount of variance in children's accuracy on mental calculation, whereas elementary arithmetic fact knowledge did not.</p>
Ganor-Stern & Weiss (2015)	<p>To investigate college students' ability to estimate the results of multi-digit multiplication problems and the extent to which this ability improves with practice.</p>	<p>The results showed that together with increase in speed and accuracy with practice, the participants also changed the strategies they used.</p> <p>The strategy analysis revealed that with practice, the participants reduced their use of the approximated calculations strategy, which involves multiplying the rounded operands and comparing the product to the reference number, and increased their reliance on the sense of magnitude strategy which does not involve any calculation but grounded in the ANS.</p>
Abreu-Mendoza & Arias-Trejo (2015)	<p>This study investigated the abilities of individuals with Down syndrome to compare area and number, and to compare them with</p>	<p>The results showed that in general, the performance of the three groups was better in the Area comparison task than in the Number comparison task. Critically, performance of individuals with Down syndrome in both tasks</p>

	those of the two control groups of typically developing individuals.	was consistent with that of individuals (normal individuals) with the same Mental age. The study shows that the abilities to compare area and numerosity are both preserved in individuals with Down syndrome, and that these individuals just like typically developing individuals, show better performance in comparing area than number.
Ziegler & Stern (2014)	Year 6 Students studying algebra often make mistakes because of superficial similarities between addition and multiplication problems. To investigate whether these errors can be prevented by presenting addition and multiplication problems in such a way that students are encouraged to compare the problems at a deeper level.	The finding in Experiment 1 at first showed that the students performed worse under the contrast condition. However, in the follow-up tests, these findings were reversed where the contrast group clearly outperformed the sequential group. The findings were replicated under improved methodological conditions in Experiment 2. These experiments showed that comparisons of superficially similar but conceptually different learning materials result in improved long-term learning. Students often have considerable difficulties in distinguishing between concepts because they are usually introduced consecutively. To help the learner distinguish between different concepts and strategies, the research had successfully introduced different concepts simultaneously by contrasting them.
Abreu-Mendoza, Soto-Alba & Arias-Trejo (2013)	To explore how the usage of different visual controls (density, total filled area, and correlated and anti-correlated areas) affect children's performance in a number of comparison tasks, and its relationship to children's cardinality knowledge.	The results showed that overall, children performed above average in the number comparison task; nonetheless, density was the easiest control, while the correlated and anti-correlated areas were the most difficult in most cases.
Sasanguie & Reynvoet (2013)	To examine the relation between the linear/logarithmic fit in a non-symbolic	In two experiments, a correlation between the estimation pattern in number line estimation and the size effect in comparison was absent. An ANOVA showed no difference between the

	number line estimation task and the size effect (SE) in a non-symbolic comparison task in first-, second- and third graders.	groups of children with a linear or a logarithmic representation considering their size effect in comparison.
Lemaire & Lecacheur (2011)	To investigate the best strategy selected by third-, fifth- and seventh graders for estimating answers to two-digit addition problems.	The findings showed that children's skill at both strategy selection and execution improved with age.
Star et al. (2010)	To evaluate the effectiveness of comparison on students' learning of Estimation; this study compared learning from comparing multiple solutions (<i>compare condition</i>) to learning from studying individually presented solutions (<i>sequential condition</i>).	The findings provide evidence of increased student flexibility and conceptual knowledge as a result of comparison; in addition, this study provides a nice example of a concrete, easily implemented technique for implementing comparison, via the side by side presentation of examples.
De Smedt, Verschaffel & Ghesquiere (2009)	To examine the relationship between a number comparison task with mathematics achievement among the first grade students.	The findings provided longitudinal evidence that the size of the individual's distance effect and calculated on the basis of reaction times in number comparison task was predictively related to mathematics achievement. Regression analyses showed that this association was independent of age, intellectual ability, and speed of number identification.
Star & Rittle-Johnson (2009)	To evaluate the benefits of supporting comparison in a classroom context for fifth and sixth grade students learning about computation estimation.	The findings showed that students who compared were more flexible problem solvers on a variety of measures. It is concluded that comparison also supported greater conceptual knowledge, but only for students who already knew some estimation strategies.

Rittle-Johnson, Star & Durkin (2009)	To investigate the importance of prior knowledge in learning from the comparison of 7 th and 8 th grade students who learned to solve equations by comparing different solution methods to the same problem, comparing different problem types solved with the same solution method, or studying the examples sequentially.	The results demonstrated that the students with prior knowledge became more flexible and improved their understanding of the procedure in learning from comparison. Comparisons of similar solution methods emphasize differences in the methods, which help to distinguish between them. In conclusion, for those with little prior knowledge of solution methods, it is best to delay comparisons of multiple solution methods. Rather, students should become familiar with at least one method, either through sequential study of examples illustrating the method or through comparison of different problems solved with the same solution method.
Star et al. (2009)	To investigate the role of students' prior knowledge of estimation strategies in the effectiveness of interventions designed to promote strategy flexibility across two recent studies.	Results indicated that students' fluency with estimation strategies had an impact on which strategies they adopted through comparison approach. Students who exhibited high fluency at pre-test were more likely to increase their use of estimation strategies that led to more accurate estimates, while students with less fluency adopted strategies that were easiest to implement.
Clarke & Roche (2009)	To compare the larger of two fractions for eight pairs mentally, giving reasons for their choice among sixth grade students.	The findings show that the successful students use benchmark (transitive) and residual thinking to solve the problem. It is concluded that students' fraction comparison strategies act as a foundation for robust understanding and possible pointers for instruction especially for development of proportional reasoning.

Based on the analysis, symbolic comparison was a robust and consistent predictor of future mathematics compare to non-symbolic comparison. The findings provide evidence of increased students flexibility and conceptual knowledge as a result of comparison.

Conclusion

The results from the analysis indicated that comparisons of numbers and comparisons of various solutions strategies are the most commonly adopted research themes in mathematical learning. Most studies focus on primary school students and all studies are done abroad. This

proves that there is a significant gap in the comparison approach in mathematical learning in Malaysia.

The findings showed that students' conceptual knowledge, procedural knowledge, and procedural flexibility are related to the greater implementation of the intervention which, when used sufficiently, can improve long-term mathematics learning (Hattikudur, Sidney, Alibali, 2016, Tavakoli, 2016; Ziegler & Stern, 2016). This study suggests that teachers may need additional support in preparing mathematics instruction using comparison approach and knowing the benefits of different types of comparison in mathematics learning may persuade and help them to decide what to compare and when to use comparison.

It is encouraging to report that using comparison approach as intervention in school settings may improve teachers' practice. In the analysis, the use of the comparison approach resulted in increased mathematic achievement compared to the use of sequential approach. To find out which types of comparison works best in mathematic learning, new research is needed in which the implementation of the interventions by the teacher plays an important role.

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