Study Note

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An Analysis of the Use of Inquiry Based Learning Through The 5E Model as A Pedagogy to Improve Critical Thinking and Problem Solving in Mathematics Education in Jamaica

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Abstract

This paper analyses the existing and restructured use of the Inquiry-Based Learning (IBL) pedagogy through the 5E model in Mathematics education in Jamaica. Mathematics education in Jamaica has been an area of concern for over a decade as data shows that many students continue to fail to meet the national standards. In order to mitigate this growing issue, the Ministry of Education, Youth and Information (MoEYI) has implemented a new curriculum, method of teaching and forms of assessment to aid in developing critical thinkers and problems solvers in the field of Mathematics and by extension, other disciplines across the curriculum. This paper examines the implemented curriculum in relation to intended curriculum by observing the existing use of 5E in comparison to a restructured 5E to determine if a difference exists that can aid in improving students' performance. The major finding is that there seems to be a gap between the theory of IBL and its implementation where online lessons for the re-structured 5E seems to be favourable to develop knowledge and skills but more favourable to develop mathematical thinking skills.

Keywords: Jamaica, National Standards Curriculum, 5E Lesson, Critical Thinking, Problem Solving

1. Introduction and Background Information

Jamaica's formal education system has been recently reformed due to evaluative reports and recommendations received from the Task Force in 2004. This is in efforts to address the current issue of low performance in Mathematics and other disciplines across the curriculum as well as to improve national competencies in relation to aligning these national standards to globally accepted STEAM/STEAM education and 21st century skills. The task force evaluation was of the former curriculum and former summative assessment tools which showed insufficient involvement of students' participation in the construction of knowledge and inadequate opportunities to apply knowledge to real world situations. (MoEYI, 2019c). It was observed by Bourne (2019) that over a fifteen -year period, the average performance for Mathematics is 54.9 % for the then Grade Six Achievement Test (GSAT).

According to a review done by Bourne (2019), as depicted in the Figure 1, the average performance for Mathematics for more than a decade is 54.9%.

As such, the educational reform includes a change in curriculum, teaching model and assessment methods. The new National Standards Curriculum (NSC) has replaced its predecessor; the Revised Primary Curriculum (PRC), by offering opportunities for students to become active participants of their learning and allows teachers to become facilitators

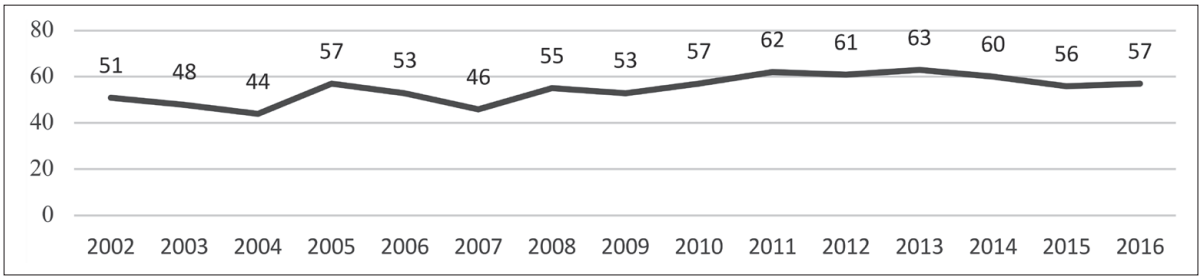


Figure1. Primary School Mathematics Performance From 2002-2016
Source: adopted from Bourne (2019) p.9.

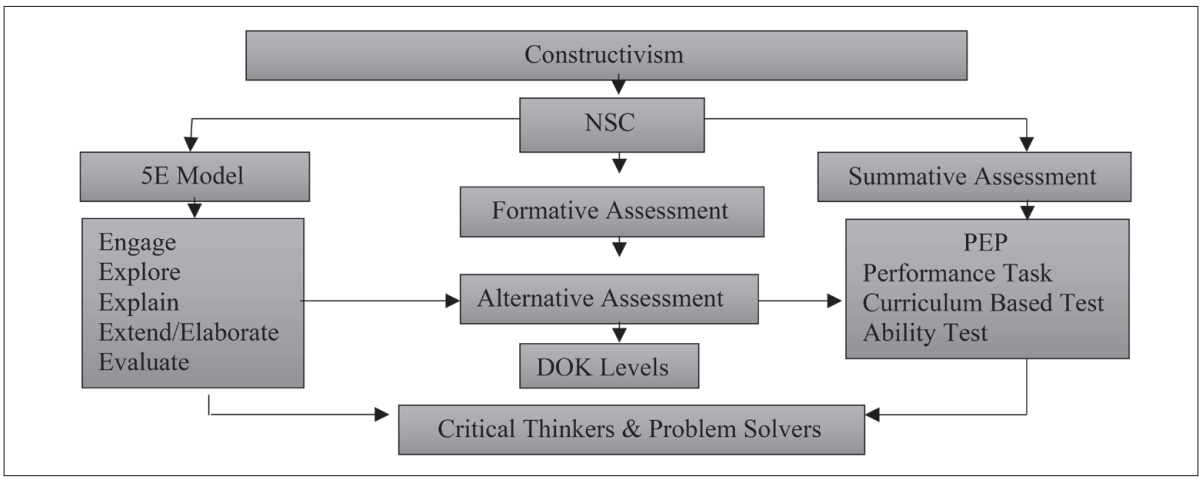


Figure 2. The NSC Framework.
Source: Created by the author according to data from MoEYI (2019)

who guide students to develop standardized competencies. The NSC's objective for Mathematics is to foster and develop key abilities/competencies: knowledge, skills and attitude in Mathematics. The current teaching method is the 5E model which is an inquiry-based strategy from a constructivist pedagogy of learning. This model consists of 5 learning cycles: engage, explore, explain, extend/elaborate and evaluate. Additionally, the Primary Exit Profile (PEP) is a series of examinations that are done at the upper primary level (grades 4-6). PEP creates an academic profile for students by highlighting all students' strengths and weaknesses and evaluates their readiness for grade seven in secondary/high school. PEP entails 3 tests: Performance Task (PT)-assess knowledge and ability in real world problems, Curriculum Based Test (CBT)- assess content knowledge and Ability test (AT)-which assess numeracy and communicative skills. PT is done at grades 4, 5 and 6 while CBT and AT are only done at grade 6. PEP evidence centred-based and incorporates Norman Webb's Depth of Knowledge (DOK) in order to assess cognitive skills and mathematical competencies (MoEYI,2019b). The conceptual framework is graphically depicted in Figure 2.

As depicted in Figure 2, the ideology of constructivism from Yelon's (1996) perspective of instructional plan which entails motivation, orientation, information, application and evaluation is reflected through the 5E model of instruction. This then requires alternative forms of assessment to develop critical thinkers and problem solvers for the focus of the curriculum. In addition, the MoEYI has also adopted a Japanese 5-step sequence of learning which starts with a review, presenting a problem (Hatsumon), individual and group solving (Kikan-shido), discussing solutions (Neriage/ Neriai) and summarizing main points (Matome). Elements of this 5-step structure are reflected in the 5E. An effective use of chalkboard practice is also referenced into the NSC from a Japanese practice of Banshoe/Bansho which utilizes the chalkboard as a point of record or reference for students to see the day's work by not erasing the contents. However, Banshoe is not practiced (MoEYI, 2019a).

2. Literature Review

Inquiry-Based Learning (IBL) is a method in teaching that is centred around guiding the learner to actively construct meaning by exploring and investigating questions or problems (Lee, 2004; Qing, Moorman & Dyjur, 2010). In addition, Staver and Bay (1987) noted that the IBL learning process is centrally focused around guidance of discovery to construct knowledge for which this guidance has three levels: structured, guided and open inquiry. In the structured inquiry, students are given a problem and method of solving. In guided inquiry, students get to choose a method for solving a problem and in open inquiry, students create their own problems and investigate solutions.

There are two primary theories that influence the development of IBL. According to McLeod (2015), psychologists Jerome Bruner further developed the existing theory of cognitive psychology which describes how people respond to stimuli into cognitive psychology of instruction which leads learners to construct knowledge and solve problems through a sequential step of instruction and exploration (Bruner, 1996). Lev Vygotsky was another psychologist who also agreed with Bruner's theory of cognitive constructivism but he extended this ideology with his theory of social constructivism as he added that learners are social beings. This notion led to the development of social constructivism instruction which leads learners to share their thoughts, ideas and experiences with each other and others as they explore and construct solutions to problems (Vygotsky, 1978). Subsequently, a fusion of these theories led to the development of IBL and the 5E instructional model of engagement, exploration, explanation, elaboration/extension and evaluation as summarized in Table 1, is a form of IBL that allows students to develop their ideas and reorganize these ideas and self-reflect throughout the learning process (Bybee & Landess,1990).

Table 1. Characteristics of 5E Learning Process

IBL -5E Learning Process	
Engage	Stimulates prior knowledge and encourages curiosity
Explore	Investigate problem and make solution
Explain	Communicate ideas and provide explanations, clarifications and self-correction
Extend/ Evaluate	Continue exploration and apply their solutions
Evaluate	Assess the extent of learning

Source: MoEYI (2019)

Inquiry-Based Learning differs from traditional methods of teaching and many teachers wonder about its effectiveness. However, educational experts and philosophers continue to stress the need for improving the mathematical literacy and competency of students in the 21st century era. As a result, many researchers have conducted studies on the implementation of IBL as a possible solution. Englen, Euler and Maass (2013) conducted a study in order to assess teachers' perspective of IBL in the European context. They found that most teachers had a positive attitude towards IBL. However, they also discovered that the daily implementation of IBL varied among the teachers which led the researchers to conclude that this could be due to differences in school systems, school structure and school system restrictions.

A research conducted by Qing, Moorman & Dyjur (2010) tested the use of an IBL model in order to examine its impact on rural students' learning in both Mathematics and Science. They found that students reported that they found the learning experience more applicable to their lives because it gave them a chance to express their ideas which increased their motivation for learning (Qing, Moorman & Dyjur, 2010). A crucial assertion made about inquiry in Mathematics is that it must be fundamentally grounded on the problem -solving aspect of Mathematics (Hiebert et.al., 1996, as cited in Betts, McLarty & Dickson, 2017). However, Michelle and Krysta (n.d., as cited in Betts, McLarty & Dickson, 2017) highlighted that the theoretical aspect of inquiry and the practice of inquiry specific to Mathematics education, and by extension other subject areas, can be sometimes disconnected due to the varied definitions and understandings of inquiry. They assert that the inquiry process entails key characteristics summarized in Table 1. They also state that although the process of inquiry is centred around guiding the learner to construct knowledge which must be facilitated during the application process in a simple and structured yet open manner, a balance of meaningful curiosity and discovery linked to the curricula objectives, key competencies and content must be maintained. If this is not done, then too much

open inquiry can result in chaotic and unfocused learning. For this reason, there is often a gap between the theoretical aspect of inquiry and the practical aspect of inquiry.

Takashi (2006) classifies what Staver & Bay (1987) describes as guided inquiry as structured inquiry which aligns with the Japanese practice of Teaching Through Problem-Solving (TTP). Though theoretical definitions of inquiry and practice may vary as noted by Betts, McLarty & Dickson (2017), the core elements outlined by Takashi of problem and solution through comparison of ideas remains constant in many approaches of IBL (Takashi 2021).

3. Purpose of Study

The aim of this study in a general sense is to gain an understanding of how the NSC is being implemented in relation to the focus of the curriculum and improvement in Mathematics performance. It also seeks to test the hypothesis that a restructured IBL will improve critical thinking and problem-solving skills in Mathematics education in Jamaica.

4. Research Questions & Framework

In order to gain an understanding of the progress of the implemented curriculum, the following questions will be asked and analysed:

1. What are some of the instructional factors that affect students' performance in Mathematics?
2. What kind of IBL lesson can be developed?
3. Has there been any improvement in the academic performances of students pre and post IBL instruction?
4. What kind of impact does IBL instruction have on the teaching and learning of Mathematics?

The theoretical framework for this study is illustrated in Figure 3. It outlines a developmental approach in order to identify possible factors that hinder the learning process and devises approaches to observe any difference in performance.

5. Research Methodology

The issue of poor performance in Mathematics education in Jamaica in areas of critical thinking and problem-solving is one that requires continuous intervention and evaluation in order to improve this mathematical crisis. The focus of this research is to understand to what extend is the possibility of utilizing Inquiry Based Learning (IBL) through the use of the 5E model as a pedagogy to improve critical thinking and problem- solving skills in Mathematics education in Jamaica. Therefore, a mixed method approach of quantitative and qualitative instruments was designed to gather data in relation to assess the problem. A mixed method approach was designed on the basis of the objective of seeking to explore and conceptualize the theoretical aim of the existing curriculum through qualitative methods as well as gaining a deeper knowledge and understanding of data gathered by classifying and quantifying them from a statistical perspective to make sense and explain what was observed, any notable differences and understand the

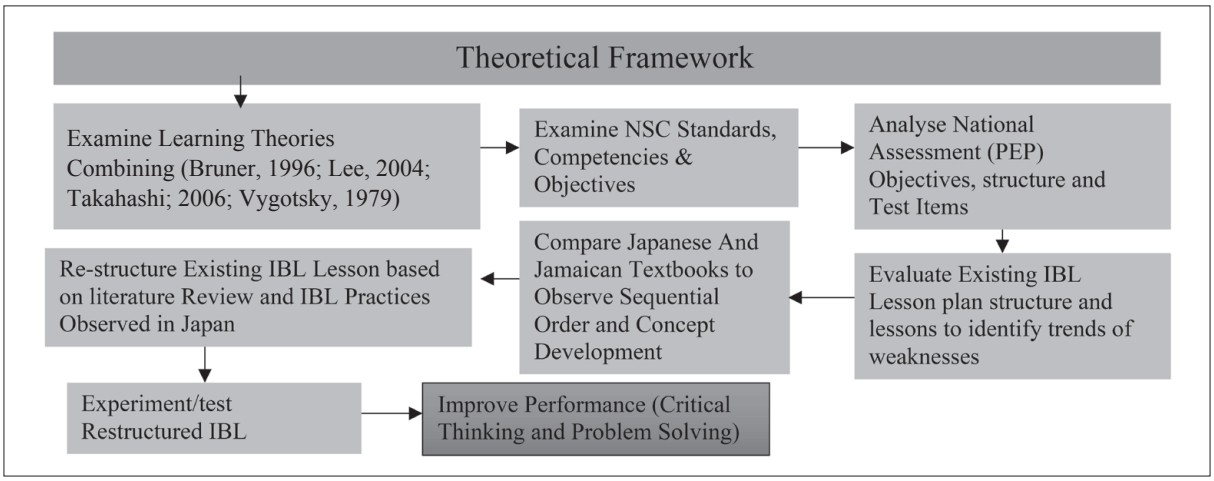


Figure 3. Theoretical Framework.
Source: Made by the author

trajectory of future implications. Quantitative instruments of data collection include pre and post-test as well as teachers' questionnaire. Qualitative methods include a semi-structured interview with a representative from the Core Curriculum Assessment Unit, national assessment analysis, textbook analysis and lesson analysis.

The research was online-based and conducted at a school in a semi- urban area. The school is categorized as a level 4 primary (elementary) school with a total of thirty (30) teachers and six-hundred and seventy-one (671) students. The study was conducted in between 2 class groups with 10 students in the controlled group and 16 students in the experimental group. Contents to be learnt is detailed in Table 2.

The comparative study for controlled and experimental lessons was screen recorded and the features of the lessons are summarized in Table3.

Students' learning achievement is evidenced through the administration of a pre and post- test that are designed in relation to the objective of the three lessons. The test design entails categorization of two pedagogical competencies which are knowledge and skill and mathematical thinking. The test has multiple choice and open- ended questions. There is a total of 7 questions on both the pre and post- test with the post-test reflecting a slight change in the ordering of the options or change in the diagram (pivoted) in order to avoid memorization of answers. A sample of the pedagogical categorization is illustrated in Figure 4.

Table 2. Leaning Contents

Topic: Line of Symmetry	Objectives: 1. Identify possible lines of symmetry on geometric shapes 2. Show the diameter of a circle as a line of symmetry 3. Identify the mirror line of reflection
Grade: 4	

Table 3. Characteristics of Lessons

Controlled		Experimental	
Engage	Activate prior knowledge	Engage	Activate prior knowledge and link to new knowledge
Explore	Investigate problem	Explore	Investigate 1 problem (individual then group)
Explain	Share ideas with explanation	Explain	Share with explanation compare
Extend/ Elaborate	Apply to new situation	Extend/ Elaborate	Apply to new situation
Evaluate	Assess extent of learning	Evaluate	Assess extent of learning (teacher and student)

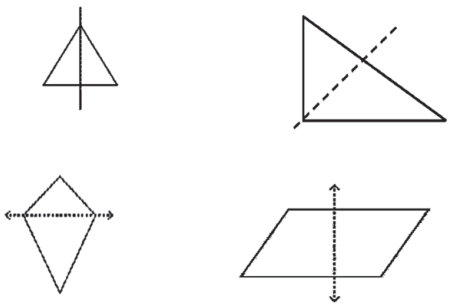
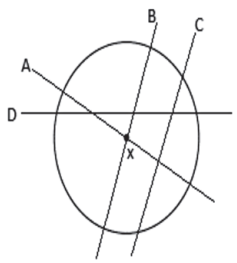
Sample of Test Questions for Different pedagogical Competencies	
Knowledge & Skill	Mathematical Thinking
Question 1 Which of the following shows a line of symmetry?	Question 6 Bella has a figure of a circle X, which lines are symmetrical?
	
	A&D A&B B&C D&C

Figure 4. Pre and Post Test Categorization.

6. Results

Data obtained from the methodological design shows several factors that impact students' mathematical performance. A semi-structured interview containing a total of nine (9) questions regarding the implementation of the NSC was conducted with a representative of the MoEYI Core Curriculum & Assessment Unit. The aim of the interview was to elicit data in relation to the developmental factors of the NSC and evaluation of its implementation. It was found that there are three main categories surrounding the implementation of the NSC as depicted below:

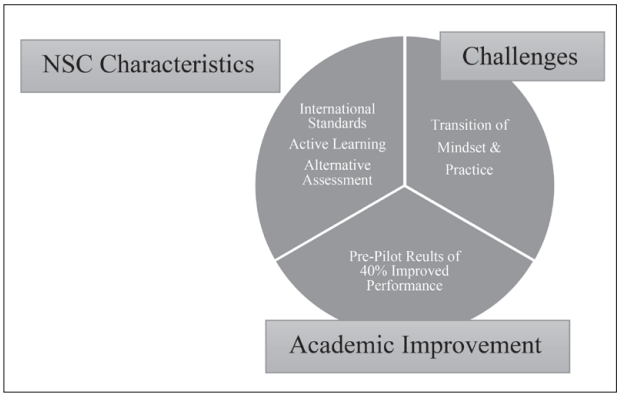


Figure 5. NSC Design & Implementation.

As illustrated in Figure 5, it was found that the NSC was developed with the consideration of developing international standards, promoting active learning and establishing alternative assessment. It was also found that the results of the pre-pilot launched the basis for the implementation of the NSC. Though the national pre-pilot results showed improved performance across the curriculum disciplines, data of the national performance, specific to the discipline of Mathematics shows that there continues to be a need to improve Mathematics performance, especially in domains of problem solving and communicating reasoning. This means that it has become necessary to further analyse the way the 5E teaching model is utilized as well as possibly considering a restructured use of the 5E teaching model.

The summary illustrated in Table 4 shows that a high percent of students at the elementary level lack basic problem solving, communicating and reasoning skills in Mathematics. In the problem- solving category, a total of 68 percent of students are ranked at the beginning and developing level. Additionally, in the communicating and reasoning category, combined total of 78 percent of the students are at the beginning and developing level. This means that only 32 and 22 percent of the nation's students are performing at the proficient and highly proficient levels in both categories respectively.

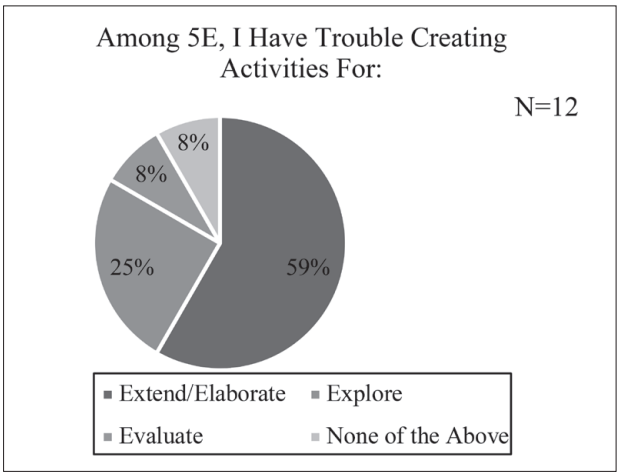


Figure 6. Difficulties Among the 5E.

Data depicted in Figure 6 shows that some teachers have difficulty creating activities for some phases of the 5E cycle. Results show that over 59% of the teachers find it difficult to create activities for extend/elaborate while 25% find it difficult to create activities for explore and another 8% s for evaluate.

Textbook analysis shows a difference in content outline for both countries where the Japanese textbook shows a more detailed information of lines of symmetry than Jamaica. The summary is illustrated

Table 4. Student Performance in the different Categories for Mathematics PEP

Mathematics				
Category	% Beginning	% Developing	% Proficient	% Highly Proficient
Problem Solving	19	49	26	6
Communicating Reasoning	32	46	15	7

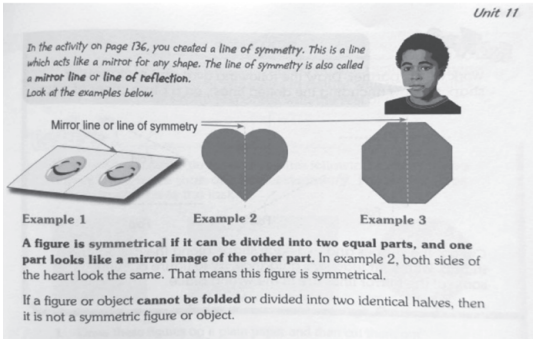
Source: MoEYI (2019c, p.29)

Textbook Content Analysis

Jamaica

Properties of line of symmetry (p.137)

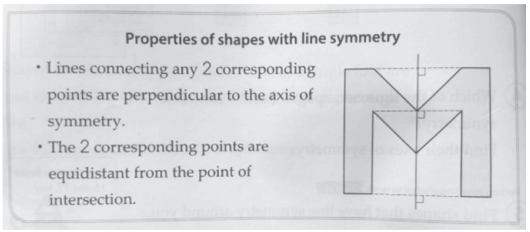
Lines of symmetry divides a shape into two equal parts or halves so that each side he has same size and shape.



Japan

Properties of line symmetry (p.10)

Lines of symmetry divides a shape into two equal parts or halves so that each side he has same size and shape. Opposing points on either side are at equal distances apart and creates a right angle when connected across the line of symmetry.



Source: Adventures for Mathematics (2019, p.137), Fun with Mathematics 6A (2012, p.10)

Figure 7. Textbook Comparison

in Figure 7.

Controlled and Experimental lessons that were conducted shows differences in practice of the 5E lesson. Among a total of 14 IBL statements that were designed to test the hypothesis, 3 main statements showed differences in practice as summarized in Table 5.

Table 5. Lesson Analysis Summary

Mathematics Content Strand: Geometry Topic: Line of Symmetry Grade 4				**Key:** **X = Not Observed** **O = Observed**			
	IBL Statements For 5E Lesson	C1	E1	C2	E2	C3	E3
G	Allow time for individual thinking	X	O	X	O	X	O
N	Learners assess the extent of their own learning	X	O	X	O	X	O

An increase in mean score for both controlled and experimental groups can be observed when comparing the pre and post test results with the experimental group showing a slightly higher mean score of .2 when compared to the controlled group and is summarized in Figure 8.

A tailed sample t-test was used to test the hypothesis and at a significance level of 0.01, no difference was found for total score which is graphically depicted in Figures 9, 10 & 11.

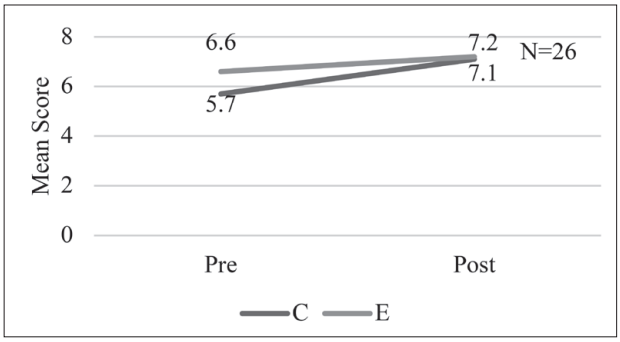


Figure 8. Pre and Post- test Comparison

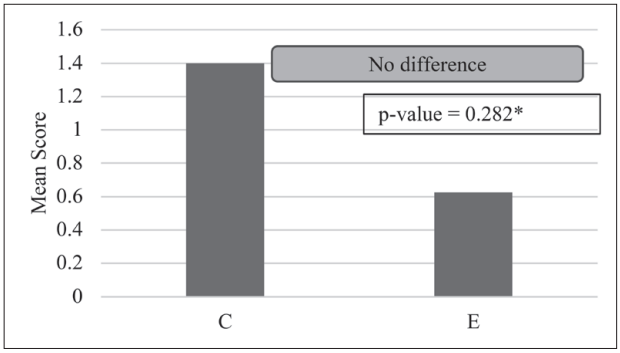


Figure 9. Comparison of Total Mean Difference

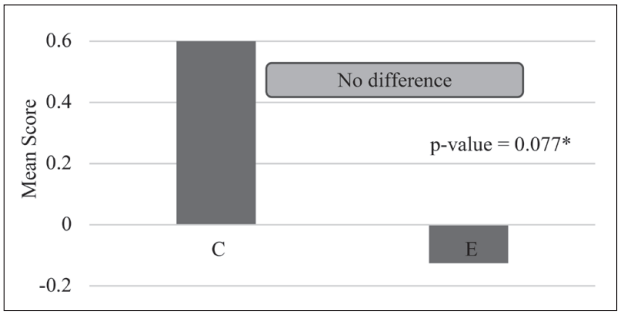


Figure 10. Improvement (Pre-Post Test Score) for Mathematical knowledge and Skill

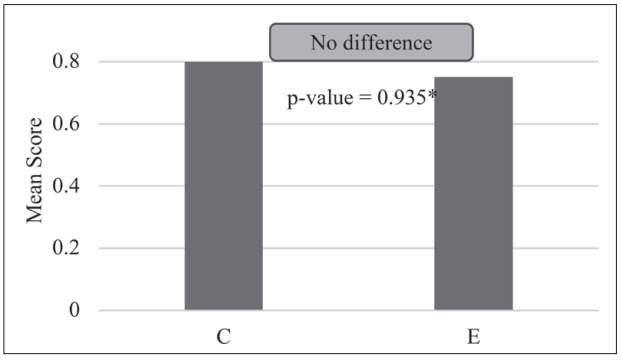


Figure 11. Improvement (Pre-Post Test Score) for Mathematical Thinking

Though the aspect of performance is statistically insignificant, there is an observed change in knowledge and skill and mathematical thinking for both controlled and experimental group as summarized in Figures 12, 13, 14 & 15.

It was found that knowledge and skill as well as mathematical thinking improved in both groups. A sample of changes observed in mathematical response for both groups is summarized in Figure 16.

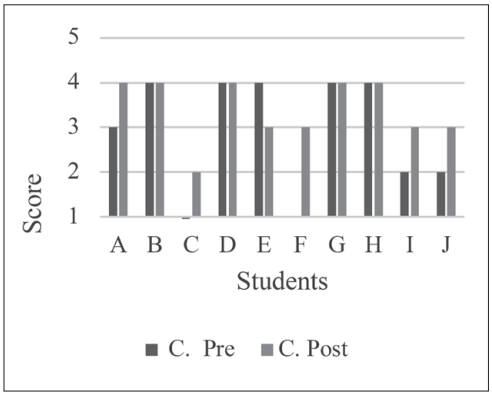


Fig 12. Know & Skill Performance for C

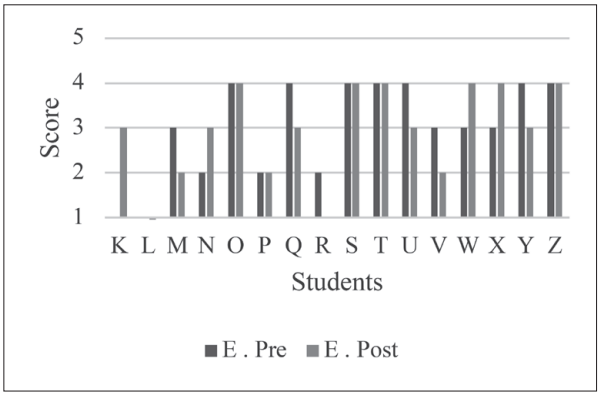


Fig 13. Know & Skill Performance for E

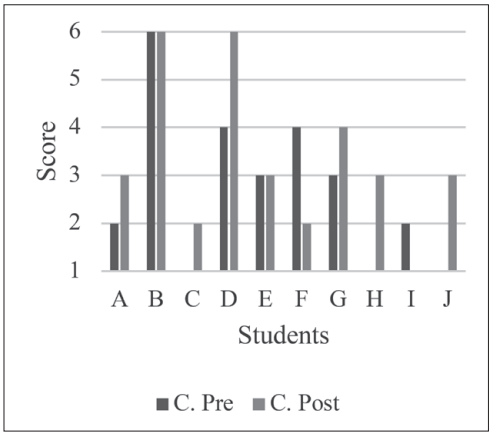


Fig 14. Mathematical Thinking for C

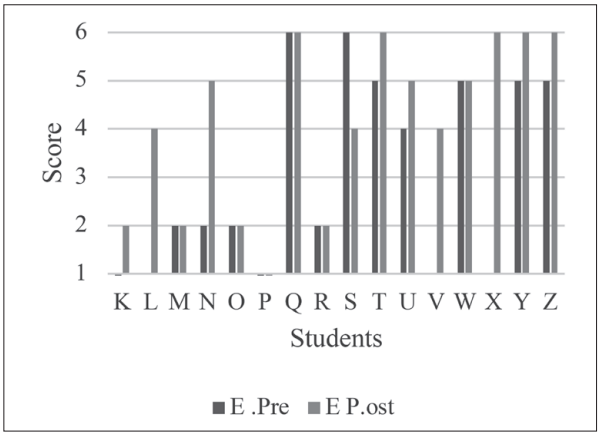
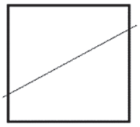


Fig 15. Mathematical Thinking for E

Question.5.
Stephen's friend, Paul, drew another picture as shown below but he didn't make it symmetrical. Explain why it is not symmetrical.



Student	Pre	Post
E	The lines are not straight and the line is not at the right side, it should go down more	Because it is not in the middle or centre
X	Because it doesn't come from a point	The line does not split the figure in half

Figure 16. Sample of Qualitative Response

7. Discussion and Conclusion

In testing the hypothesis that a restructured IBL will improve critical thinking and problem -solving skills, the data shows no significant difference for pre and post-test. This could be affected by the number of participants (26) as this small size made it difficult to detect any effect that may have occurred and may cause a skewing in results. Online technicalities may possibly affect student's attendance and motivation which may also affect results. In addition, there seems to be a gap between the intended curriculum and the implemented curriculum. As shown in Figure 5, a transition of teachers' mindset and practise is a possible detected determinant to question 1. Figure 7 shows a difference in content analysis from the textbook comparison between Jamaica and Japan which is also possible answer to question 1. Additionally, results from Figure 6 show difficulties that teachers have among the 5E. These collective findings can be interpreted as possible instructional factors that affect performance in Mathematics. With regards to incorporating elements of a redesigned structure and practise of IBL through the 5E model from a Japanese perspective, Table 5 illustrates some of the key elements that can be developed into the lesson in reference to question 2. Additionally, Table 4 and Figures 9, 10 & 11 provide results for the academic performance and shows no great improvement at the national level as well as no significant improvement at a sampled class level in relation to question 3. However, Figures 12,13, 14, 15 & 16 illustrate the kind of impact that IBL can have on learning in regards to question 4 which is that IBL can improve student's knowledge and skill and well as mathematical thinking skills. In conclusion online lessons for the re-structured 5E seems to be favourable to develop knowledge and skills but more favourable to develop mathematical thinking skills as observed from the data.

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