Study Note

NUE Journal of International Educational Cooperation, Volume 15, 83-90, 2021

Assessing Mathematics Academic Ability at the Elementary Level in El Salvador Based on Cognitive and Content Domains: Combining TIMSS's Framework and El Salvador Mathematics Curriculum

Ana Ester ARGUETA ARANDA, Francisco Antonio MEJÍA RAMOS, Satoshi KUSAKA, Hiroki ISHIZAKA

Global Education Course, Graduate School, Naruto University of Education

Abstract

This paper addresses the assessment of the students' academic ability in El Salvador, by defining it considering previous contributions. Academic ability has been considered as the students' cognitive skills as a consequence of how well children have been taught about the curricular contents; some results from a total of 3981 students in 6th grade at elementary schools in El Salvador were analyzed. Achievement level in academic ability can be considered as adequate in some domains with accuracy percentages above 50%, but worrying in some other domains like *geometry*, or *reasoning* with 29% and 25% correspondingly. Finally, some insights are presented about the trends of students' responses and relationship with the way that they were probably taught.

Keywords: El Salvador, Mathematics Assessment Framework, Academic Ability, Content domains, Cognitive domains.

1. Introduction

The search of establishing education systems of good quality is a duty for most of the countries and governments, with a special mention for developing countries. El Salvador has been working on improving mathematics education, by implementing changes on the syllabuses for all the grades, and concretizing such changes by providing textbooks for public schools (MoE, 2020; Mejia & Ishizaka, 2019). As mentioned by Maruyama & Kurosaki (2021), this intervention was focused on implementing Japanese teaching style contextualization to El Salvador mathematics lessons. Currently, the Ministry of Education of El Salvador is working on developing a National Evaluation System. These efforts can be enhanced with the present study, which aims to assess the academic ability of students at the elementary level in El Salvador.

First of all, this paper will cover a range of different approaches for defining *academic ability* as a construct to be measured, in this case through a test-based assessment. The term itself is complex and some authors endow it with a very wide range of considerations, while other instances try to keep it simpler, to the point that the concept is near to be synonym of *cognitive skills*. For this study, efforts will be made to keep it simple so that it can be affordable and measurable, but incorporating some considerations posed by authors who consider the term to be wider. The framework of this research is designed according to that definition.

Defining properly the *content domains* based on curricular contents (MoE, 2018a; 2018b) and the *cognitive domains* based on *cognitive skills* emphasized in El Salvador textbooks and the TIMSS assessment framework for mathematics (Mullis & Martin, 2017) is key in developing the assessment test of this study with certain grade of validity. A second relevant point for conducting this research was the development of good items corresponding adequately to the tasks related to the *cognitive domains* and balancing them among the different *content domains* as well. Moreover, preparing the different choices for each item was important to allow this study to trace, somehow, the way that students were taught based on their performance and selected responses.

2. Review of the Literature

Assessment in education has a relatively recent incursion, it can be related to the main contributions done during 19th and 20th centuries (Linden, 2017). Moreover, testing culture has gained popularity in recent years, and many countries have enhanced their assessment systems in many ways depending on cultural aspects and context (e.g., Kuramoto & Koizumi, 2018; Cooper, 1998; Drijvers, Kodde-Buitenhuis, & Doorman, 2019). Discussion about the features of large-scale assessment have several approaches in different academic fields; for instance, Kuramoto & Koizumi (2018) addressed some important points referred to what is assessed and how is it assessed, and how theses aspects influence the purpose of the assessment and the assessment format. In order to state the structure of our assessment it is also needed to mention that it is more related to the *Principle of Education* mentioned by Kuramoto & Koizumi (2018) which is linked with the claims of many scholars that assessment should be primarily used to improve learning (Nortvedt & Buchholtz, 2018). Therefore, this paper has focused the measurement of the *academic ability* construct through the cognitive skills and curricular contents attained by students at the elementary level.

The term *academic ability* has been widely related to teaching practices and assessment or research (Smith, 2021). In this sense, some authors like Smith (2021) and York, Gibson, & Rankin (2015) have pointed out about how some other terms like achievement, attitude, intelligence (Smith, 2021) or academic success, academic achievement, student success, student learning (York, Gibson, & Rankin, 2015) can be close related to academic ability. Then, following only some dimensions which compressed the term academic ability in Smith (2021), it has been understood as the students' cognitive skills as a consequence of how well children have been taught. Developing assessment is a continuous task in many instances, nationals as well as internationals, and several points should be considered to develop national assessment systems that provide information of students' academic achievements.

The mathematics education of El Salvador has been highly influenced by the Japanese style in recent years, it can be observed in previous works (Maruyama & Kurosaki, 2021; Mejia & Ishizaka, 2019). Then, some tasks are influenced by the way that the National Assessment of Academic Ability (NAAA) try to examine the academic achievement. While it is true that many issues were stated by Kuramoto & Koizumi's work (2018), some of them are difficult to tackle in this research. In order to better define a way in which the framework is to be assessed, some other contributions are taken from Mullis & Martin (2017). Measuring *academic ability* in this opportunity is used only as a *diagnostic measurenment* to detect main misconceptions of students. Some efforts in measuring students learning have been carried out in El Salvador in the last years, but still refinament should be done on them to assure the improvement of the education.

The Learning and Aptitudes Test for High School Graduates (PAES, for its acronym in Spanish) is a standardized test in El Salvador for 11th grade students; one of its aims is to identify the level of development of skills, abilities and capacities stated by the national curriculum in four subjects: mathematics, social studies, natural science and Spanish (MoE, 2019c). PAES classifies its items on three levels (basic, intermediate and superior) to measure cognitive skills according to the revised Bloom's taxonomy.

In 2019, some of the challenges and difficulties identified in mathematics were related to the hierarchy of basic operations, algebraic expressions, domain and range of a function, and data interpretation (MoE, 2019c). Due to the fact that PAES is carried out until 11th grade and it is the only national standardized assessment in El Salvador, what could be the relevance of its results for elementary or junior high school, in terms to measure students' academic ability? If one of the students' misconceptions in mathematics detected by PAES is related to basic operations, information about elementary school students' achievements is significant to improve El Salvador's mathematics education and curriculum.

3. Research Questions and Framework

The present paper aims to provide a first trial that can be consider as a proposal to enhance the National Evaluation System of El Salvador. This study proposes a framework for measuring *academic ability* at the elementary level as a consequence of how well children have been taught, and the type of items associated to the different domains. The trial results are shown and analyzed to finally deepen the analysis of common misconceptions. The questions that this study aims to provide answers for are:

1. How do students perform in the different *content domains?*
2. How do students perform in the different *cognitive domains?*
3. What kind of answers' trends are related to the items belonging to the lowest performed domains?

In order to identify students' performance in both, *content domains* and *cognitive domains*, the trial was designed based on the assessment frameworks of the Trends in International Mathematics and Science Study (TIMSS) and the curriculum of El Salvador. One of the characteristics of TIMSS is that it uses the broadly defined curriculum to inquire about students' educational opportunities: "*what is actually taught in classrooms*…; *and, finally, what it is that students have learned*…" (Mullis & Martin, 2017); its assessment framework involves a content dimension related to the subject matter to be assessed, *content domains*, and a cognitive dimension regarding the thinking processes, *cognitive domains* (Mullis & Martin, 2017).

The four *content domains* considered to be assessed by the trial were those main contents in mathematics established by the syllabuses of El Salvador: arithmetic, geometry, measurement, and statistic (MoE, 2018a; MoE, 2018b). In case of the *cognitive domains*, TIMSS defines three thinking processes in mathematics and science: knowing, applying and reasoning (Mullis & Martin, 2017); linking them with the context of El Salvador's mathematic education through the implemented textbooks for elementary school, the definition per cognitive domain is as follows:

- Knowing: covers the facts, concepts, and procedures students need to know.
- Applying: focuses on the ability of students to apply knowledge and conceptual understanding to solve problems or answer questions.
- Reasoning: goes beyond the solution of common problems to encompass complex situations, integrating different contents and multistep problems.

In order to link the present definition of *cognitive domains*, and El Salvador curriculum and PAES assessment framework through the revised Bloom's taxonomy, it is considered the correspondence proposed by Lee & Huh (2014). The six cognitive processes in the revised Bloom's taxonomy resemble TIMSS measurement of student academic achievement in mathematics is showed in Table 1.

Table 1. Cognitive process based on the revised Bloom's taxonomy and TIMSS assessment framework

Revised Bloom's taxonomy					
Rote learning	Meaningful learning				
Remember	Understand	Apply	Analyze	Evaluate	Create
Recognizing Recalling	Interpreting Exemplifying Classifying Summarizing Inferring Comparing Explaining	Executing Implementing	Differentiating Organizing Attributing	Checking Critiquing	Generating Planning Producing
TIMSS assessment framework					
Knowing	Applying		Reasoning		N/A
Recalling Recognizing Computing Retrieving Measuring Classifying	Selecting Representing Modeling Implementing Solving routine problems		Analyzing Generalizing Synthesizing Justifying Solving non-routine problems		

Data source: Lee & Huh (2014, p.289)

Lastly, by considering the previous definitions, it was constructed the Figure 1, which basically represents the construct that this assessment is aiming to measure. It can be understood as the *cognitive skills* that have been measured with the instrument through the *curricular contents* acquired by how students have been taught. The *content domains* represent the mathematics curriculum strands, and are studied in research question 1; the *cognitive domains* are represented by the *cognitive skills* defined above, and studied in research question 2; to deepen in the understanding about how students have been taught, it is studied the students' responses trends related to research question 3.

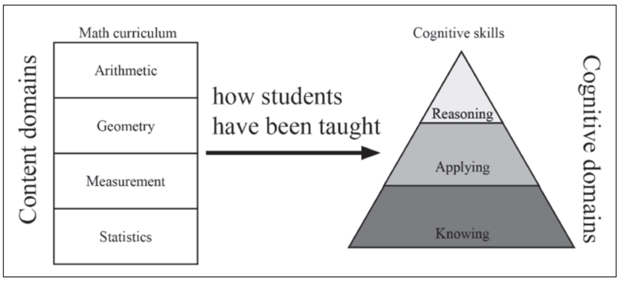

Figure 1. Academic ability framework
Data source: Elaborated by authors

4. Methodology

The purpose of this research is to measure mathematics academic ability based on collecting content and cognitive domains and relating them to students' response trends. In this sense, a test was developed to measure the construct defined on Figure 1, by gathering information about the three dimensions before mentioned, contents domains attainment level, cognitive skill, and describing the kind of trends that follow incorrect answers from students.

In measuring the different dimensions of the construct, developing appropriate tasks or good items is key for the validity of the study. The items are, mainly, multiple choice; each item has been categorized in both dimensions, content and cognitive domains. The different choices for each item are important to conduct a further analysis for responding research question 3. For research question 1 and 2, a descriptive statistical method has been used for calculating the accuracy rate for each item; the score for each domain in both dimensions was calculated by cumulating the correct answers from the corresponding items. On the other hand, for research question 3, a qualitative analysis has been conducted based on the incorrect choices selected by students, and relating them to possible class situation issues that could happened when students were taught.

This study was conducted in November 2020, during pandemic situation, with 6th grade students. To avoid the impact of the change of education during COVID-19 influence, the curricular content to be assessed covers from 1st to 5th curricular contents, emphasizing, mostly, the second term of elementary school. The test was conducted online through Google Forms, and it is compressed by 21 items distributed per content and cognitive domains following the Table 2. A sample in English version of the test items designed is retrieved in the following link: https://forms.gle/EXYUrwZbeCjn2PH76; the test was originally conducted in Spanish. Also, this study considers only one open-ended question, to measure to what extent can this kind of items be applicable in future studies; however, such item was not focused for the further analysis.

Table 2. Specification of the test

	Knowing	Application	Reasoning	Total
Arithmetic	5	4	1	10
Geometry	2	0	3	5
Measurement	1	3	0	4
Statistics	1	1	0	2
Total	9	8	4	21

The test was available for one week, and students could submit their responses through any kind of electronic device. The total of net responses was 5675, and after debugging the database (due to repetition) the total is 3981. Students from about 800 schools participated in this study.

5. Results

5.1. Quantitative results

By looking at Figure 2, it is noticeable that the accuracy percentage per content domain obtained by the test showed that students have more difficulties or misconceptions in geometry, since it only reached 29% of correct answers. The rest of content domains obtained an accuracy percentage equal or more than 60%.

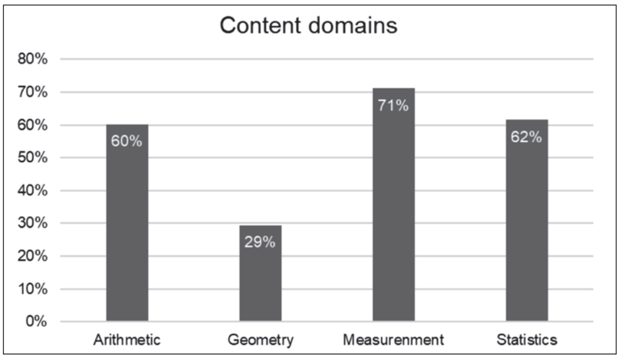

Figure 2. Accuracy percentage per content domain
Data source: Elaborated by authors

In case of cognitive domains, Figure 3 shows the performance in them; reasoning obtained an accuracy percentage of only 25%, while knowing and application are both upper 50% of correct answers. This can be considered as appropriate for application domain after just some years of changes implemented by ESMATE, but a bit low for knowing domain, which usually can be expected to surpass 80%.

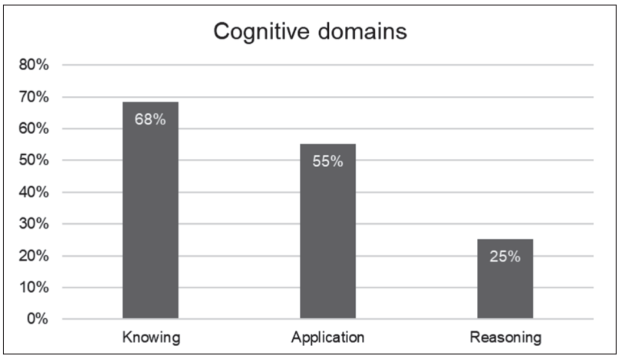

Figure 3. Accuracy percentage per cognitive domain
Data source: Elaborated by authors

The general results per content and cognitive domain are showed in Table 3. As can be observed, the knowing domain is affected by the low performance in geometry. Also, the application domain seems to be increased by a high accuracy in measurement, which probably is related to the familiar context on those items. A limitation for this study is that the application domain in geometry was not measured due to technical issues.

Table 3. Accuracy percentage per content and cognitive domain

	Knowing	Application	Reasoning	Average
Arithmetic	74%	47%	44%	60%
Geometry	45%		19%	29%
Measurement	76%	70%		71%
Statistics	79%	44%		62%
Average	68%	55%	25%	55%

Finally, some of the items gathered accuracy percentages lower than 35%, such is the case of items 3, 8, 11 and 13 presented in Table 4. These items are qualitatively analyzed in the next section, and they stand for arithmetic and geometry specially, which are also more emphasized in the courses of study (about 74% and 14% correspondingly). Same items also the three cognitive domains, and two of them are related to reasoning domain which performed lower, as observed in Figure 3.

Table 4. Accuracy percentage of items 3, 8, 11 and 13

Item	3	8	11	13
Total correct answers per item	1091	667	1284	969
Percentage of correct answers	28%	17%	32%	24%

5.2. Qualitative results

This section presents some trends in items with lower accuracy rate. The aim of this analysis is to trace how students have been taught. For this purpose, the items mentioned in Table 4 are considered and deeply analyzed. For the further analysis the factor of which content was not taught is not mentioned and should be a general consideration for all the contents that were assessed.

The item 3 is related to addition of unlike fractions, and the distribution of responses among the different choices can be reviewed in Figure 4. Even though this item corresponds to the knowing domain, it was one of the lowest performed by students. The correct answer was option d, however 55% of students selected the option b as the correct answer. This means that many students add fractions by adding numerator with numerator and denominator with denominator. In this sense, probably at the moment that the content was taught, it was not considered to reflect on the reason that makes (for example) that $\frac{1}{2}+\frac{1}{3}=\frac{2}{5}$ is a contradiction. Mentioning the addition sense at elementary school, this operation is always related to an increasing total. Then, the fact that $\frac{2}{5}$ would be bigger than $\frac{1}{2}$ should be intuitively contradictory, even by using visual resources or liquids addition context that are often described on El Salvador textbooks (MoE, 2019a, p. 146-152).

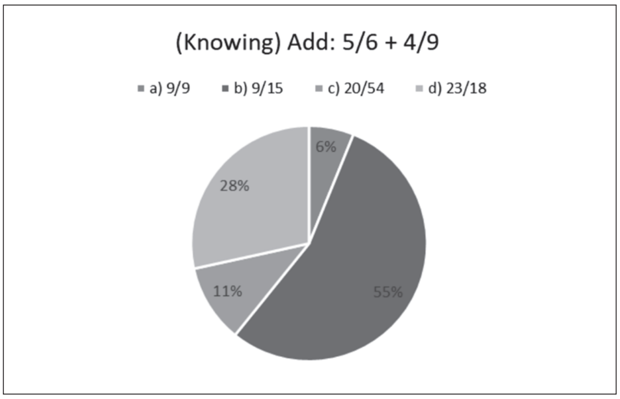

Figure 4. Distribution of percentages for item 3
Data source: Elaborated by authors

Applying domain also had an item related to arithmetic, in which students performed lower. The item 8 just had about a 17% of accuracy rate (option d), but many students selected option b or c; in Figure 5 can be observed that. For students that selected option b, maybe they were clear about $\frac{14}{15}$ should be bigger than $\frac{2}{15}$, however probably they are not clear about that $1\frac{1}{15}$ is bigger than 1. In the textbook (MoE, 2019a, p.151) is needed to address how 1 can be expressed as $\frac{1}{1}=\frac{2}{2}=\cdots=\frac{15}{15}=\cdots$. In this sense, student could realize that just having a whole number 1 in $1\frac{1}{15}$, means that they already have $\frac{15}{15}$, which is bigger than $\frac{14}{15}$. Related to students who chose option c, probably they understand that the whole number in the mixed number is already bigger than any proper fraction. The misconception in this option comes in comparing unlike fractions $\frac{1}{15}$ and $\frac{1}{3}$ accompaning the whole number. Therefore, maybe students would compare them in a better way if they would know how to apply equivalent fractions, just by converting $\frac{1}{3}=\frac{5}{15}$ and comparing like fractions. The key factor from this item is that the multiple ways to express a fraction (equivalent fractions) to represent whole numbers and quantities should be a key point in teaching fractions topics at the elementary level.

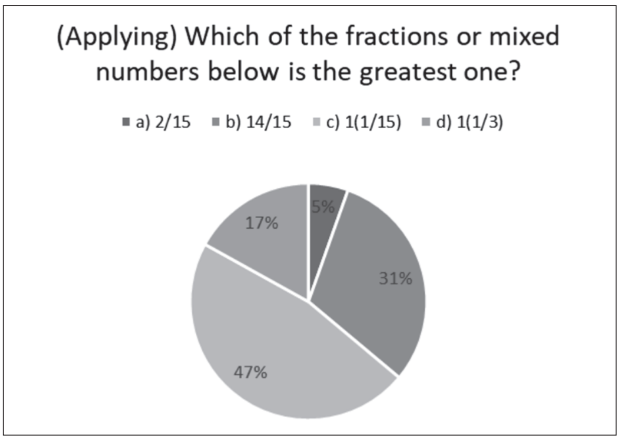

Figure 5. Distribution of percentages for item 8
Data source: Elaborated by authors

Item 11 belongs to geometry and the knowing domain, and the distribution of responses among the different choices can be reviewed in Figure 6. It presented five 3-D shapes, as showed in Figure 7, the correct answer was option b, which obtained 33% of correct answers, but 43% of students selected option d that included the prisms and the pyramid. There exists a lack of understanding about the definition of prism, and the difference between it and a pyramid. Although these contents are taught in 4th and 5th grade in El Salvador, there is not a lesson in textbooks that include a comparison between 3-D shapes to identify differences among them (MoE, 2019a, 46-47; MoE, 2019b, 172-182).

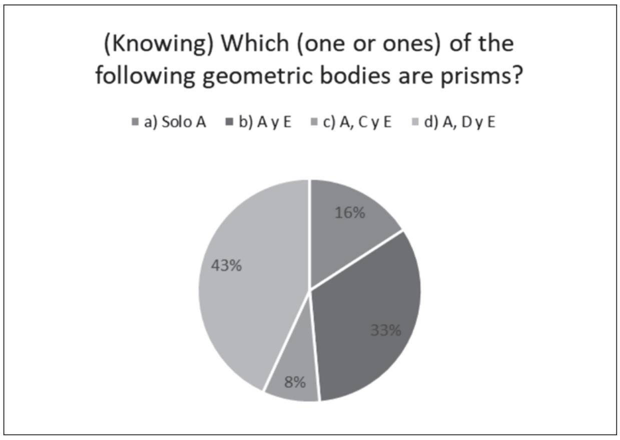

Figure 6. Distribution of percentages for item 11
Data source: Elaborated by authors

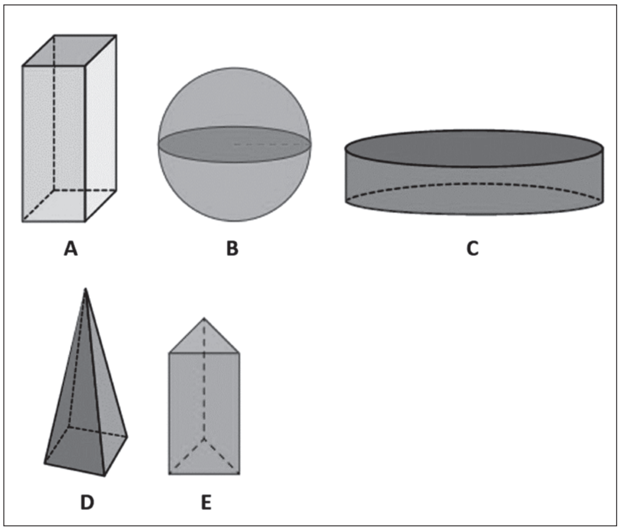

Figure 7. 3-D shapes for item 11
Data source: Elaborated by authors

Item 13 is related to the property of the internal angles of a triangle; its distribution of responses among the different choices can be reviewed in Figure 8. This item belongs to the reasoning domain, and the correct answer is option d. Based on the percentages obtained for each option, student selected it randomly and they could not integrate the property about the sum of the internal angles of a triangle with the classification of angles depending on their size. Like item 8, even though both contents are taught separately (MoE, 2019a, 24-25; MoE, 2019b, p. 31), the lesson in El Salvador textbooks can be improved by adding these kinds of integrated problems.

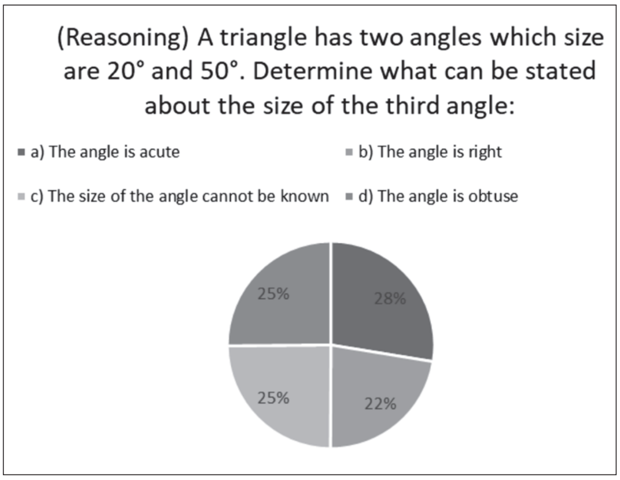

Figure 8. Distribution of percentages for item 13
Data source: Elaborated by authors

6. Conclusions

First of all, while it is true that students' performance throughout the different content domains could be considered as appropriate (reaching about 60% or more), it should be observed and addressed that they have struggles in geometry (29%). The topics assessed on this content domain were referred to 3-D shapes, area, angles and cube nets, which are relevant contents to be learned at the elementary school.

Secondly, from the cognitive domains' performance it can be concluded that knowing skills would be expected to have a higher accuracy percentage, probably more than 80% could be accepted as appropriate. On the other hand, the reasoning domain had a very low performance (25%), which means that students are not used to justifying, integrating different contents, and analyzing through attributing an abstraction (e.g., cube) belonging to an entity (e.g., net).

Lastly, it seems that the responses trends of students in the topics of fractions, 3-D shapes, and angles have a close relationship with the way that students were taught. Operations with fractions, especially addition of unlike fractions and how misconceptions about this topic are addressed during the lesson delivery might be very important, also the feature that fractions can be expressed and many multiple ways as equivalents can be worthwhile. On the other hand, spatial thinking in visualizing 3-D shapes maybe can be improved by using various resources such as ICT tools (when available), manipulatives, and probably the allocation of time for this topic. Therefore, it is likely that promoting activities that integrate different topics to solve a specific problem could improve students' reasoning skills.

7. References

Cooper, B. (1998). Assessing national curriculum mathematics in england: exploring children's interpretation of key stage 2 tests in clinical interviews. *Educational Studies in Mathematics*, Vol35(1), pp.19-49.

Drijvers, P., Kodde-Buitenhuis, H. & Doorman, M. (2019). Assessing mathematical thinking as part of curriculum reform in the Netherlands. *Educational Studies in Mathematics*, Vol.102(5-6), pp.435–456. doi:https://doi.org/10.1007/s10649-019-09905-7

Kuramoto, N. & Koizumi, R. (2018). Current issues in large-scale educational assessment in Japan: focus on national assessment of academic ability and university entrance examinations. *Assessment in education: Principles, Policy & Practice*, Vol.16(3), pp.415-433. doi:https://doi.org/10.1080/0969594X.2016.1225667

Lee, D. & Huh, Y. (2014). What TIMSS tells us about instructional practice in K-12 Mathematics education. *Contemporary Educational Technology*, Vol.5(4), pp.286-301.

Linden, W.J. (2017). Introduction. In W.J. Linden, *Handbook of Item Response Theory, Volume One: Models* (pp. 1-10). California: Chapman & Hall/CRC Statistics in the Social and Behavioral Sciences.

Maruyama, T. & Kurosaki, T. (2021). Developing

Textbooks to Improve Student Math Learning: Empirical Evidence from El Salvador. *JICA Research Institute*., Working Papers 217. doi:DOI: 10.18884/00001041

Mejia, F. & Ishizaka, H. (2019). Effectiveness and Issues of ESMATE (Project of Making New Mathematics Textbooks for Primary and Secondary Schools): Contextualization of the Japanese Teaching Style Materials to Current Learning Situation in El Salvador. *NUE Journal of International Education Cooperation*, Vol.13, pp.47-55. doi:10.24727/00028536

Ministry of Education (2018a). *Mathematics. Course of Study. Lower Primary Education [Matemática. Programa de Estudio. Primer Ciclo de Educación Básica]*. San Salvador, San Salvador, El Salvador: Ministry of Education of El Salvador.

Ministry of Education (2018b). *Mathematics. Course of Study. Upper Primary Education [Matemática. Programa de Estudio. Segundo Ciclo de Educación Básica]*. San Salvador, San Salvador, El Salvador: Ministry of Education of El Salvador.

Ministry of Education (2019a). *Mathematics 4, ESMATE textbook [Matemática 4, Libro de texto ESMATE]*. San Salvador: Ministry of Education of El Salvador.

Ministry of Education (2019b). *Mathematics 5, ESMATE textbook [Matemática 5, Libro de texto ESMATE]*. San Salvador: Ministry of Education of El Salvador.

Ministry of Education (2019c). *PAES 2019 Report of results [Informe de resultados PAES 2019]*. San Salvador: Ministry of Education of El Salvador.

Ministry of Education (2020). *ESMATE systematization [Sistematización de ESMATE]*. San Salvador: Ministry of Education of El Salvador.

Mullis. I.V.S., & Martin, M.O. (Eds.). (2017). TIMSS 2019 Assessment frameworks. Retrieved from Boston College, TIMSS & PIRLS international Study Center website: http://timssandpirls.bc.edu/timss2019/frameworks/

Nortvedt, G.A. & Buchholtz, N. (2018). Assessment in mathematics education: responding to issues. *ZDM Mathematics Education*, Vol.50, pp.555-570. doi:https://doi.org/10.1007/s11858-018-0963-z

Smith, L.M. (2021). The ability trap: reductionist theorising about academic ability and the ramifications for education policy and school-based practice. *Cambridge Journal of Education*, Vol.51(1), pp.85-103. doi:https://doi.org/10.1080/0305764X.2020.1782351

York, T.T., Gibson, C. & Rankin, S. (2015). Defining and Measuring Academic Success. *Practical Assessment, Research & Evaluation*, Vol.20, Article 5. doi:DOI: https://doi.org/10.7275/hz5x-tx03