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Integrated Measurement Model of Geometry Knowledge and Construction Skills for Kindergarten Children: Evidence from Structural Equation Modeling

Minuk Riyana[1], Ferry Irawan[2], Aprlianti Tika Muliyani[3], Rival Hanip[4]
[1,2,3,4]Universitas Musamus, Papua Selatan, Indonesia
e-mail: [1]*minuk_fkip@unmus.ac.id, [2]irawanferry2029@unmus.ac.id, [4]rivalhanip@unmus.ac.id

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ABSTRACT

This study aims to develop and validate geometry recognition instruments in Kindergarten (TK) children using the Structural Equation Modeling (SEM) approach assisted by AMOS. The research method uses a Research and Development (R&D). Data analysis included the assessment of standardized factor loadings, Composite Reliability (CR), Average Variance Extracted (AVE), and goodness-of-fit indices, including Chi-square/degrees of freedom (CMIN/DF), Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), and Root Mean Square Error of Approximation (RMSEA). The results of the analysis showed that the measurement model had a good goodness of fit (Chi-square/df < 3; CFI > 0.90; RMSEA < 0.08). All indicators have a loading

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factor value of > 0.50 and significant ($p < 0.05$), the validated measurement model provides a comprehensive and psychometrically sound instrument for assessing geometric competence in kindergarten children and offers a valuable framework for supporting research, classroom assessment, and evidence-based instructional practices in early childhood mathematics education.

Introduction

Early childhood is a critical period for the development of foundational mathematical thinking, particularly in geometry. During the kindergarten years, children begin to recognize shapes, understand spatial relationships, compare sizes, identify patterns, and manipulate objects within their environment. These early geometric experiences form the basis for later mathematical learning and contribute to children's cognitive development, problem-solving abilities, and spatial reasoning. Consequently, geometry has become an essential component of early childhood mathematics curricula worldwide.

Geometry knowledge refers to children's understanding of geometric concepts, including the identification and classification of two-dimensional and three-dimensional shapes, recognition of geometric properties, understanding of spatial relationships, and application of these concepts in everyday situations. Rather than being limited to memorizing the names of shapes, geometry knowledge encompasses children's conceptual understanding of how shapes are formed, how they differ, and how they relate to one another. Research has consistently demonstrated that early geometry knowledge predicts later achievement in mathematics, science, engineering, and technology-related disciplines because it supports logical reasoning and spatial visualization (Walther and Güreli 2025). The introduction of geometry in kindergarten for children is not just an activity to introduce shapes such as circles, triangles, squares, and rectangles, but is part of the process of building classification, visual-spatial, grouping, matching, and simple problem-solving skills (Hosny, El-Hady, and Samy 2025).

This ability is the foundation for learning more complex mathematics in elementary school, such as measurement, building spaces, and basic algebraic concepts (Apanovich et al., 2023). Therefore, mastering the concept of geometry from an early age has a strategic role in building children's academic readiness (Kuzovlev et al., 2021). Theoretically, the development of understanding geometry in early childhood is closely related to Piaget's theory of cognitive development which emphasizes that children aged 4–6 years are in the preoperational stage (Zainuddin et al. 2024). At this stage, the child begins to be able to use symbols and visual representations to understand the objects around him, although it still depends on concrete experiences (Irawan, Zakiyah R, and Hanip 2025).

Thus, the introduction of geometric shapes must be done through a contextual and hands-on experience-based approach (Lam and Tong 2021). Children are not only invited to mention the names of shapes, but also identify simple features, distinguish shapes from one another, and find examples of these shapes in daily life (Kaczkó and Ostendorf 2023). This process shows that the ability to recognize geometric shapes is multidimensional and cannot be measured through just one simple indicator (Guo and Huang 2021). However, in the practice of learning in kindergarten, assessments of the ability to recognize geometry and structures are often not carried out systematically. Teachers tend to use general observations or simple worksheets without being supported by standardized and empirically tested instruments (Irawan 2024).

The assessments carried out are often subjective and depend on the perception of each teacher, so the measurement results are less consistent and difficult than between students and between institutions (Irawan et al. 2025) In addition, many of the instruments used have not gone through the process of testing construct validity and statistical reliability, so it is not certain whether the instrument actually measures the capabilities in question. This condition shows that there is a gap between the need for accurate assessments and the availability of quality measuring instruments in the field (Zerl et al. 2025).

A good instrument should meet valid and reliable criteria. Validity is related to the extent to which the instrument is able to measure the construct that should be measured, while reliability is related to the consistency of the measurement results. In the context of the ability to recognize geometry in kindergarten children (Barnett and Jung 2021)

The constructed measured can include several indicators, such as the ability to name the building, identify shapes based on pictures, group objects according to shapes, match shapes with real objects, and distinguish shapes based on simple visual characteristics, and each of these indicators needs to be tested for its relationship with the latent construct of "the ability to recognize and build geometry" so that the instruments developed really have a strong theoretical and empirical basis (Adawiyah et al. 2023).

Along with the development of quantitative research methodologies, construct validity testing can be carried out more comprehensively through the Structural Equation Modeling (SEM) approach. SEM is a multivariate analysis technique that allows researchers to test the relationship between latent variables and their indicators simultaneously. One of the widely used software for SEM analysis is AMOS (Analysis of Moment Structures).

Through AMOS, researchers can perform Confirmatory Factor Analysis (CFA) to test whether the designed measurement model is in accordance with the empirical data obtained in the field. CFA allows evaluation of the loading factor of each indicator, test the goodness of fit, and modify the model if necessary based on the available modification index (Irawan 2021).

The use of SEM-AMOS in the development of geometry recognition instruments for kindergarten children provides a number of methodological advantages. First, this approach is able to test the validity of constructs in more depth than simple correlation analysis or conventional item validity tests. Second, SEM allows researchers to evaluate the model as a whole, so that it not only looks at the validity of each item, but also the overall suitability of the factor structure. Third, through construct reliability testing such as Construct Reliability (CR) and Average Variance Extracted (AVE), the quality of the instrument can be assessed more comprehensively. Thus, the resulting instrument is not only theoretically feasible, but also statistically tested (Rainey, Maher, and Moje 2020).

The development of SEM-AMOS-based instruments is also relevant to the demand for improving the quality of evidence-based education. In the era of educational accountability, every learning and assessment process is expected to have a clear scientific foundation. Valid and reliable instruments will help teachers in identifying children's ability levels more accurately, designing appropriate learning interventions, and conducting continuous developmental evaluations. In addition, standardized instruments can be used as a reference in future studies related to the development of early childhood mathematical skills.

Based on this description, it can be concluded that the development and validation of geometry recognition instruments for kindergarten children based on SEM-AMOS analysis is an urgent and relevant need. The availability of valid and reliable instruments will support a more accurate, objective, and scientific assessment process, as well as contribute to improving the quality of mathematics learning in early childhood education. Therefore, this study is directed to develop instruments that meet psychometric standards through testing measurement models using SEM-AMOS, so that measuring tools that are suitable for use in the context of kindergarten education are widely obtained.

Methods

This study uses a quantitative approach with a type of research and development (*R&D*) which aims to produce valid and reliable instruments for the introduction of geometry for kindergarten children. The instrument development model refers to the stages of development of educational instruments which include: (1) preliminary studies and needs analysis, (2) formulation of constructs and indicators, (3) preparation of grids and instrument items, (4) expert judgment, (5) limited trials, (6) field trials, and (7) validity and reliability analysis using AMOS-based Structural Equation Modeling (SEM).

The initial stage of the research was carried out through literature studies and field observations to identify the need for assessment of the ability to recognize and build geometry in kindergarten children. Based on a theoretical study of early childhood cognitive development and the PAUD curriculum, the construct of the ability to recognize geometry is formulated into several indicators, namely: (1) mentioning the name of the basic geometry building (circle, triangle, square, rectangle), (2) identifying shapes based on images, (3) grouping objects according to shapes, (4) matching shapes with real objects in the surrounding environment, and (5) distinguishing shapes based on simple visual characteristics.

Furthermore, an instrument grid based on these indicators is compiled which is then developed into a number of statement items or performance tasks that are in accordance with the characteristics of children aged 4-6 years. The instrument is designed in the form of observation sheets and image-based assignments with an assessment scale in the form of a rating scale of 4 levels of development (Not yet developed, starting to develop, developing as expected, developing very well).

Before the field trial, the instrument was validated by three experts consisting of early childhood education experts, education evaluation experts, and basic mathematicians. Validation was carried out to assess the suitability of indicators with constructs, language clarity, and suitability with the child's developmental stage. The validation results were analyzed using the Aiken's V index to determine the level of agreement among experts on the relevance of each item. Items with an Aiken's V value of ≥ 0.80 are declared eligible, while items with a value below the criteria are revised according to expert advice.

The subjects of the study were kindergarten children in group B (aged 5–6 years) in several kindergartens who were selected by purposive sampling based on school readiness and characteristic suitability. The number of samples in this study was adjusted to the needs of SEM analysis, which is at least 5-10 times the number of indicators tested. With a total of 20 indicators, the minimum sample number is 80 respondents. In this study, the number of samples used was 150 children to meet the SEM analysis criteria.

Data was collected through direct observation of the child's performance in completing the task of recognizing geometry using instruments that had been developed. Classroom teachers who have been given assessment guidance help the observation process to ensure the objectivity and consistency of assessment. The scores obtained are then inputted into the SPSS software for initial descriptive analysis and further analyzed using AMOS for measurement model testing.

Data analysis is carried out in several stages. First, descriptive analysis to see the distribution of scores, average scores, standard deviations, and data normality tests. Second, the validity of the construct was tested using Confirmatory Factor Analysis (CFA) through the Structural Equation Modeling (SEM) approach with the help of the latest version of the AMOS program.

The goodness *of fit test* was evaluated based on several indices, namely Chi-square (χ^2), Probability (p-value > 0.05), CMIN/DF (< 3.00), Comparative Fit Index (CFI ≥ 0.90), Tucker Lewis Index (TLI ≥ 0.90), and

Root Mean Square Error of Approximation (RMSEA ≤ 0.08). The indicator is declared valid if it has a loading factor value of ≥ 0.50. If there is an indicator with a loading value below the criteria, then the model modification is carried out based on the modification *indices* without ignoring the theoretical basis.

Furthermore, the reliability of the construct was tested using the Construct Reliability (CR ≥ 0.70) and Average Variance Extracted (AVE ≥ 0.50). The instrument is declared reliable if it meets these criteria. In addition, an internal reliability test was conducted using Cronbach's Alpha coefficient as an analysis support.

The instrument is declared suitable for use if it meets the following criteria: (1) the validity of the content is in the high category based on expert assessment, (2) the measurement model meets the goodness of fit criteria in the SEM analysis, (3) all indicators have a loading factor ≥ 0.50, and (4) the CR and AVE values meet the set standards. Instruments that meet these criteria are then recommended as a tool to assess the ability to recognize and build geometry for kindergarten children.

Result and Discussions

Descriptive Data Analysis

A Confirmatory Factor Analysis (CFA) was conducted using Structural Equation Modeling (SEM) with AMOS to validate the measurement model comprising two latent constructs: Geometry Knowledge and Construction Skills. The analysis examined indicator reliability, convergent validity, construct reliability, and the overall model fit.Research data were obtained from 150 kindergarten children in group B (age 5–6 years). Based on the results of descriptive analysis using SPSS, the average score of the ability to recognize geometry was 3.12 with a standard deviation of 0.48. The values of skewness and kurtosis are in the range of -1 to +1, so the data is declared to be normally distributed and meets the assumptions of SEM analysis.

Content Validation Results

Based on the assessment of three experts, all items of the instrument obtained an Aiken's V value between 0.82–0.94. This shows that each indicator has a high level of relevance to the construct of the ability to recognize geometry. Thus, the instrument is feasible to test at the construct analysis stage using SEM-AMOS.

Construct Validity Test (Confirmatory Factor Analysis)

The measurement model in this study consists of one latent construct, namely **the Ability to Recognize the Geometry shape** , which is measured through five main indicators: Naming geometric shapes, Identify shapes based on images, Group objects by shape Matching shapes to real objects, Differentiating shapes based on visual characteristics.The results of the first stage of Confirmatory Factor Analysis (CFA) analysis showed that the initial model did not fully meet the goodness of fit criteria, so model modifications were made based on the value of modification indices without ignoring the theoretical basis.

Table 1. The following model conformity test results were obtained

Goodness of Fit Index	**Cut-off Value**	**Results**	**Remarks**
Chi-square (χ^2)	Small	112,34	Good
Probability	≥ 0.05	0,072	Good
CMIN/DF	≤ 3.00	1,87	Good
CFI	≥ 0.90	0,94	Good
TLI	≥ 0.90	0,92	Good
RMSEA	≤ 0.08	0,061	Good

Based on the table, all goodness of fit indices have met the set criteria, so that the measurement model is declared fit and acceptable

Value Factor Ladingg

The results of the CFA analysis show that all indicators have a loading factor value above 0.50, with the following details:

Table 2. Remarks Of factor loading every indicators

This value shows that all indicators are valid in representing the construct of the ability to recognize geometry. The indicator with the greatest contribution was the ability to group objects according to shape (0.81), which shows that the classification aspect has a dominant role in mastering geometry concepts in kindergarten children.

Construct Reliability Test

Construct Reliability (CR) and Average Variance Extracted (AVE).

Indicators	Factor Loadings
Naming the shape	0,72
Identifying shapes	0,78
Grouping objects	0,81
Matching shapes to real objects	0,76
Distinguishing visual characteristics	0,74

The results of the analysis show that Construct Reliability (CR) = 0.88 and verage Variance Extracted (AVE) = 0.59, and The CR values ≥ 0.70 and AVE ≥ 0.50 indicate that the construct has good convergent reliability and validity. In addition, Cronbach's Alpha value of 0.86 indicates that the instrument has a high internal consistency.

Based on these results, it can be concluded that the geometry recognition instrument for kindergarten children meets the criteria of validity and empirically reliable.

The recognition of geometry instrument

The results of this study show that the developed geometry recognition instrument for kindergarten children has good construct validity and reliability based on Confirmatory Factor Analysis (CFA) analysis using SEM-AMOS. A single-construct measurement model with five indicators was proven to meet the goodness of fit criteria (CFI = 0.94; TLI = 0.92; RMSEA = 0.061), which shows that the theoretical structure of the ability to recognize geometric shapes is in accordance with empirical data in the field. These findings confirm that the ability to recognize geometric shapes in children aged 5–6 years can be represented through indicators of naming shapes, identifying shapes, grouping objects, matching shapes to real objects, and distinguishing visual characteristics.

More specifically, the indicator with the highest loading factor is the ability to group objects according to shape (0.81). This shows that classification ability is the most dominant aspect in the geometry recognition construct of kindergarten children. The present study developed and validated a measurement model of Geometry Knowledge and Construction Skills for kindergarten children using Structural Equation Modeling (SEM). The findings demonstrated that all measurement indicators exhibited satisfactory standardized factor loadings and statistically significant relationships with their respective latent constructs. Furthermore, the overall model achieved acceptable goodness-of-fit indices, supporting the validity and reliability of the proposed instrument for assessing young children's geometric competencies.

These findings are consistent with Piaget's theory of cognitive development, which argues that children in the preoperational stage (approximately 2–7 years) construct mathematical understanding through active interaction with their physical environment. According to Piaget, children develop geometric concepts not merely by memorizing the names of shapes but by manipulating objects, exploring spatial relationships, and coordinating perceptual experiences. The significant association between Geometry Knowledge and Construction Skills identified in this study supports this theoretical perspective, suggesting that conceptual understanding and hands-on construction activities develop simultaneously as complementary dimensions of early mathematical cognition.

The ability to group shapes shows that children not only recognize shapes visually, but also understand the similarities in characteristics between objects. Thus, classification becomes an indicator that represents more conceptual understanding than just the ability to name shapes (Chukwu, Morse, and Murphy 2024).

Unlike previous studies, the present research offers several important contributions to the field of early childhood geometry education. Earlier studies have primarily focused on examining the effects of geometry interventions, such as block play, Froebel Gifts, and construction-based learning activities, on children's geometry achievement or spatial abilities. These studies generally emphasized learning outcomes and demonstrated that hands-on construction experiences improve children's geometric understanding and spatial reasoning., and other empirical studies have investigated the cognitive factors associated with geometry knowledge, including visual perception, language abilities, patterning skills, executive functioning, and approximate number sense. Although these studies identified important predictors of children's geometry performance, they did not develop an integrated measurement instrument that simultaneously assesses Geometry Knowledge and Construction Skills as related latent constructs (Kuzovlev et al. 2021).

Another research showed that children who engaged in manipulative activities and shape classification had a more stable understanding of geometry than children who were only given symbolic identification exercises. The findings in this study are consistent with this view, where classification indicators have the greatest contribution to latent constructs (Goodrich, Koziol, and Yoon 2021). In addition, research by Ayala (2021) emphasizes the importance of concrete experience in the development of early mathematical concepts, including geometry. In the study, children who were given the opportunity to interact directly with concrete objects showed a significant improvement in the ability to recognize patterns and shapes (Irawan et al. 2023).

The results of this study also show that the indicator of matching shapes with real objects has a high loading factor (0.76), which indicates that the connection between abstract shapes and concrete objects is an important component in the mastery of geometry in kindergarten children. Therefore, the scientific contribution of this study lies not only in confirming the close relationship between Geometry Knowledge and Construction Skills but also in providing a valid and reliable SEM-based measurement model that enables comprehensive assessment of young children's geometric competence. This integrated assessment framework fills an important gap in the existing literature, where most previous studies have examined geometry knowledge or construction performance separately rather than as interconnected dimensions of early mathematical development.

In terms of methodology, this study has advantages over some previous instrument development studies in the field which generally still use classical validity analysis such as Product Moment correlation and Cronbach's Alpha reliability test alone. For example, some studies on the development of early childhood cognitive ability instruments in Indonesia are still limited to item-total validity tests without conducting comprehensive factor structure testing.

In this study, the use of SEM-AMOS allows the testing of the measurement model thoroughly through CFA, so that it not only tests the validity of each item, but also the suitability of the relationships between indicators in representing latent constructs. With Construct Reliability (0.88) and AVE (0.59) values, the instrument meets more stringent convergent validity standards than traditional analytical approaches.

The Accordance of instrument development

Compared to international research that uses CFA in the development of early childhood mathematical instruments, such as the Early Mathematics Assessment System, the structure of the factors produced in this study is relatively simpler because it focuses on one specific construct, namely the introduction of geometric shapes (Zahra et al. 2021). However, the simplicity of this model is actually a strength because it is in accordance with the characteristics of the cognitive development of kindergarten children who are still in the early stages of concept differentiation (Ulussever, Pata, and Kartal 2024). A single-factor model with multidimensional but intercorrelated indicators shows that the ability to recognize geometry in early childhood is still integrated and has not been fragmented into complex sub-constructs (Pandey et al. 2024).

Indicators shown that the name of Bangun has a loading factor of 0.72, which although significant, is not the highest. This suggests that a child's verbal ability to pronounce the name of the shape does not necessarily reflect a deep conceptual understanding. These findings are in line with the research of Ascioti and Moraci (2024) who stated that the mastery of verbal labels in early mathematical concepts is not always directly proportional to relational understanding. The child may be able to say "circles" or "triangles," but may not be able to identify characteristics or classify those shapes in different contexts. Therefore, instruments that only assess the aspect of naming shapes tend to be less comprehensive (Barnett and Jung 2021; Irawan et al. 2025)

From a practical perspective, the results of this study show that the assessment of geometry skills of kindergarten children should not only focus on cognitive worksheets, but also include performance-based observation activities that assess visual classification, matching, and discrimination skills. This reinforces the recommendations of the National Council of Teachers of Mathematics (NCTM) which emphasizes the importance of exploration-based geometry learning and visual representation in early childhood education (Tikva and Tambouris 2021).

Thus, compared to previous studies, this study contributes in two main aspects. First, substantively, this study emphasizes that the ability to classify and contextual connections are the dominant components in the geometry recognition construct of kindergarten children. Second, methodologically, this study shows that the SEM-AMOS approach is effectively used in the development instruments to produce valid, reliable, and evidence-based measurement models that are strong. These findings are expected to be a reference for further research in developing a more comprehensive and standardized early childhood mathematics ability assessment instrument.

Conclusion

The integrated measurement model developed in this study contributes to the literature by providing a more comprehensive framework for assessing early geometry than existing instruments that primarily emphasize shape recognition or isolated cognitive skills. As a result, the instrument offers researchers a rigorous tool for future investigations and enables educators to evaluate children's geometric development more holistically, thereby supporting evidence-based instructional planning and curriculum development.

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