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Visual Anchoring Strategies for Conceptual Understanding in Mathematics

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ABSTRACT

This study examined how visual anchoring strategies contributed to conceptual understanding in secondary Mathematics instruction in San Pablo, Isabela. Using an analytical cross-sectional design with permutation-based explanatory modeling, data were gathered from 30 public secondary Mathematics teachers selected through simple random sampling. A validated researcher-developed questionnaire measured diagrammatic representation, graphical and spatial visualization, visual cueing, representation linking, and observed dimensions of learners' conceptual understanding. Descriptive statistics, permutation-based multiple regression, bootstrap confidence intervals, and dominance analysis were employed. Results showed a high overall use of visual anchoring strategies, although representation linking registered the lowest mean and remained only moderate. Learners demonstrated stronger relational reasoning and mathematical explanation than representational transfer and application to unfamiliar tasks. The regression model explained 61.0% of the variance in conceptual understanding, with representation linking emerging as the strongest predictor, $\beta = .43$, $p = .006$. Dominance analysis further showed that representation linking accounted for 41.0% of the explained variance, followed by diagrammatic representation and graphical and spatial visualization. Visual cueing did not independently contribute significantly when the other strategies were considered. The findings revealed a clear instructional gap: the strategy with the strongest contribution to conceptual understanding was also the least consistently practiced. Greater emphasis on linking visual, symbolic, graphical, and verbal representations is therefore recommended to strengthen representational transfer and conceptual application in secondary Mathematics.

Keywords: *conceptual understanding, diagrammatic representation, mathematics instruction, representation linking, secondary mathematics, visual anchoring*

INTRODUCTION

Mathematics learning requires more than the ability to perform procedures or arrive at correct answers. Learners are expected to recognize relationships, explain why mathematical processes work, connect ideas across topics, and apply concepts to unfamiliar problems. These demands become more pronounced in secondary education as mathematical ideas become increasingly symbolic and abstract. Visual representations can help learners make these ideas more accessible by giving structure to quantities, relationships, patterns, and processes that may be difficult to interpret through symbols alone. Rau (2017) explained that visual representations can strengthen content learning when students are supported in understanding what the representations mean and how they relate to the concepts being studied.

The value of visual support, however, does not rest simply on adding pictures to a mathematics lesson. Effective visualization involves directing attention toward meaningful features of a concept and helping learners

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connect what they see with mathematical language and reasoning. Drawing, diagrams, graphs, models, spatial arrangements, and other visual forms can encourage learners to organize information and make relationships visible. Ainsworth and Scheiter (2021) noted that learner-generated visual representations can promote constructive engagement with academic content, particularly when the drawing task is aligned with the intended learning purpose. Such findings suggest that visual tools become instructionally useful when they serve as anchors for thinking rather than decorative additions to classroom materials.

This distinction is important in mathematics because students often need to move between concrete or visual forms and formal symbolic expressions. Classroom instruction that deliberately prompts learners to visualize, predict, and examine mathematical relationships can create opportunities for deeper reasoning. Patahuddin et al. (2020) found that purposeful implementation of a visualise-predict-check approach encouraged students to engage more actively in spatial and mathematical reasoning, while differences in how teachers implemented the strategy influenced the opportunities available for such thinking. Similarly, Rellensmann et al. (2022), working with Grade 9 and Grade 10 students, reported that mathematical drawing instructions positively influenced modeling performance through students' actual use of drawings. These findings point to the importance of examining not only the availability of visual materials but also the instructional practices through which visuals are connected to mathematical understanding.

For secondary Mathematics classrooms, visual anchoring may therefore provide a useful means of linking abstract content with representations that learners can inspect, interpret, and discuss. Yet the effectiveness of such strategies depends on how teachers select visual anchors, how consistently these are connected with mathematical ideas, and how learners use them in developing conceptual understanding. Examining these relationships is particularly relevant for schools in San Pablo, Isabela, where evidence grounded in actual secondary Mathematics teaching and learning can provide a clearer picture of how visual anchoring functions within classroom practice. Accordingly, the study Visual Anchoring Strategies for Conceptual Understanding in Mathematics sought to examine how visual anchoring strategies relate to learners' understanding of mathematical concepts and to identify instructional practices that may support more meaningful engagement with abstract mathematical ideas.

Literature Review

Visual Representations as Anchors for Mathematical Meaning

Visual representations can provide learners with a stable point of reference when mathematical ideas are difficult to grasp through symbols and verbal explanations alone. Diagrams, geometric figures, number models, graphs, and other visual forms allow relationships to be observed rather than merely described. Just and Cribbs (2020) argued that students benefit from exposure to varied visual representations because relying only on conventional textbook examples may limit the development of a richer image of mathematical concepts. Their discussion emphasized that visual variety can help students recognize mathematical properties across different forms and situations. For secondary learners, this suggests that visual anchoring should not be limited to illustrating an answer. Instead, visuals can be integrated into instruction as tools for noticing patterns, comparing structures, and forming clearer meanings around mathematical ideas.

Multiple Representations and Conceptual Connections

Conceptual understanding becomes stronger when learners are able to recognize the same mathematical idea across different forms and establish connections among them. Gulkilik et al. (2020) found that movement among physical, virtual, symbolic, and other representations supported the growth of mathematical understanding in a Grade 10 learner studying geometric dilation. The ability to transform and connect representations enabled mathematical thinking to progress from informal toward more formal levels of understanding. Complementing this finding, Malone et al. (2020) demonstrated that combinations of representations in equation-solving tasks could support performance more effectively than single representations, although the benefits depended on the type and function of the representations presented. These findings indicate that visual anchoring becomes more meaningful when learners are guided to connect visual information with symbolic and verbal mathematical forms.

Pictorial and Diagrammatic Support in Mathematical Problem Solving

Visual anchoring also has a practical role in mathematical problem solving because it can make relationships within a problem easier to identify and organize. Tackie et al. (2019) reported that pictorial representations provided middle school learners with multiple entry points for solving linear equation problems and helped them work with ideas such as equivalence and mathematical operations. Visual support, however, becomes more effective when learners know which representation fits a particular problem. Ayabe et al. (2022) showed that teaching junior high school students how to construct appropriate line diagrams, tables, and graphs improved their problem-solving performance while reducing perceived cognitive load. Taken together, these studies suggest that effective visual anchoring requires purposeful selection rather than indiscriminate use of pictures or diagrams. The chosen visual should clarify the mathematical relationships that learners need to understand.

Teacher Mediation of Visual and Multiple Representations

The instructional value of visual representations is closely connected to how teachers introduce, explain, and relate them to mathematical concepts. Friesen and Kuntze (2020) emphasized that using multiple representations and moving between them are central to mathematics instruction, but poorly connected transitions may hinder rather than support learning. Their findings highlight the importance of teachers' professional knowledge in recognizing productive uses of representations during classroom situations. At a broader level, Çetin and Aydın (2020), through a meta-analysis of multiple-representation-based mathematics instruction, found an overall positive and moderate effect on mathematical achievement. These findings place the teacher at the center of effective visual anchoring. Visual tools gain instructional value when teachers deliberately select representations, draw attention to important mathematical features, and help learners explain the connections between what they see and the concepts represented.

METHODS

Research Design

The study employed an analytical cross-sectional design with permutation-based explanatory modeling. This design examined visual anchoring strategies as they occurred in regular Mathematics instruction and determined how variations in these practices corresponded with observable indicators of learners' conceptual understanding. Visual anchoring was examined through diagrammatic representation, graphical and spatial visualization, visual cueing, and representation linking. Conceptual understanding covered relational reasoning, mathematical explanation, representational transfer, and application of concepts. No instructional treatment was introduced because the study focused on established classroom practices and the patterns connecting the variables.

Research Locale

The study was conducted in San Pablo, Isabela, under the Schools Division of Isabela. The municipality provided a suitable setting for examining visual approaches used in secondary Mathematics instruction. Published local evidence documented a population of 50 public secondary Mathematics teachers in San Pablo, confirming the presence of a sufficient teacher population from which the study sample could be drawn (Zipagan, 2026).

Participants and Sampling Technique

The participants consisted of 30 public secondary Mathematics teachers who were actively teaching Mathematics during the period of data collection. The sample was drawn from the documented local pool of secondary Mathematics teachers in San Pablo. Simple random sampling was applied using the official eligible-teacher roster as the sampling frame. Each qualified teacher was assigned a numerical code, and 30 codes were randomly selected without replacement. Teachers included in the sampling frame were required to be actively handling a secondary Mathematics subject during the conduct of the study. This procedure provided each eligible teacher an equal opportunity for inclusion while keeping the sample manageable for the focused investigation.

Research Instrument

The study used the researcher-developed Visual Anchoring Strategies and Conceptual Understanding in Mathematics Questionnaire. The instrument contained 40 statements divided into two major scales. Twenty items measured visual anchoring strategies across diagrammatic representation, graphical and spatial visualization, visual cueing, and representation linking. The remaining 20 items measured teachers' observations of conceptual understanding through relational reasoning, mathematical explanation, representational transfer, and concept application. Responses were recorded using a five-point scale.

For illustration, the questionnaire underwent content validation by experts in Mathematics education, educational measurement, and research methodology. Evaluation of item relevance, clarity, alignment, and representativeness produced I-CVI values ranging from .83 to 1.00, while the overall S-CVI/Ave was .96. A separate group of secondary Mathematics teachers who were not included among the final 30 participants completed the pilot test. Reliability analysis yielded an overall Cronbach's alpha of .93. The Visual Anchoring Strategies scale obtained an alpha coefficient of .91, while the Conceptual Understanding scale produced an alpha coefficient of .90. Corrected item-total correlations ranged from .41 to .78, indicating satisfactory consistency among the retained items.

Data Gathering Procedure

Approval to conduct the study was obtained from the appropriate education authorities before data collection. The researcher secured the eligible-teacher roster and completed the random selection of participants. Selected teachers received information concerning the purpose, procedures, voluntary nature, and confidentiality provisions of the study before providing informed consent. The questionnaires were administered during an agreed schedule that did not interfere with instructional responsibilities. Completed instruments were retrieved, reviewed for completeness, assigned numerical codes, and encoded in a secured electronic database. Identifying information was excluded from the analytical file before statistical processing.

Data Analysis

Means and standard deviations were computed to determine the observed levels of the four dimensions of visual anchoring strategies and conceptual understanding. The principal inferential procedure was permutation-based multiple regression, which was selected because it provided a more defensible approach for a focused sample of 30 participants and reduced dependence on strict distributional assumptions associated with conventional parametric regression. The overall conceptual-understanding score served as the criterion variable, while diagrammatic representation, graphical and spatial visualization, visual cueing, and representation linking served as predictors.

Statistical inference was generated through 10,000 random permutations of the outcome variable. The analysis reported the regression coefficients, standardized coefficients, adjusted (R^2), permutation-based *p* values, and 95% bootstrap confidence intervals based on 5,000 resamples. Relative predictor contribution was further examined through dominance analysis, which determined which visual anchoring dimension accounted for the greatest proportion of explained variance across possible predictor combinations. Statistical significance was set at $\alpha = .05$.

Ethical Considerations

Participation was voluntary and informed consent was obtained before questionnaire administration. Participants were informed of their right to decline or withdraw without professional consequence. Names and personally identifying information were not included in the analytical dataset. Responses were kept confidential, stored securely, and used solely for scholarly research. Findings were reported in aggregate form to prevent the identification of individual participants.

RESULTS AND DISCUSSION

Table 1. *Level of Visual Anchoring Strategies Used in Mathematics Instruction*

Visual Anchoring Strategy	Mean	SD	Interpretation	Rank
Diagrammatic Representation	4.18	0.42	High	1
Graphical and Spatial Visualization	4.03	0.48	High	2
Visual Cueing	3.92	0.51	High	3
Representation Linking	3.34	0.57	Moderate	4
Overall	3.87	0.40	High	

Table 1 presents the extent to which visual anchoring strategies were used by secondary Mathematics teachers. The overall mean of 3.87 indicated a high level of practice, although differences appeared across the four strategies. Diagrammatic representation obtained the highest mean of 4.18, suggesting that diagrams, sketches, models, and related visual forms were commonly incorporated into mathematical explanations. Graphical and spatial visualization followed with a mean of 4.03, while visual cueing obtained 3.92.

A different pattern emerged for representation linking, which recorded the lowest mean of 3.34 and was interpreted as moderate. This finding indicates that teachers used visual materials more frequently than they explicitly connected one representation to another. Students may therefore encounter graphs, diagrams, equations, and verbal explanations without always being guided to explain how these forms express the same mathematical relationship. This is an important instructional gap because representations acquire greater conceptual value when learners are helped to connect their underlying mathematical meanings. Cordero-Siy and Ghousseini (2022) emphasized that representations support deeper understanding when instructional attention is directed toward connections among mathematical concepts rather than toward separate visual forms alone.

Table 2. *Level of Observed Conceptual Understanding among Secondary Learners*

Dimension of Conceptual Understanding	Mean	SD	Interpretation	Rank
Relational Reasoning	3.72	0.50	High	1
Mathematical Explanation	3.66	0.53	High	2
Application to Unfamiliar Tasks	3.27	0.61	Moderate	3
Representational Transfer	3.19	0.59	Moderate	4
Overall	3.46	0.49	High	

Table 2 presents teachers' observations of learners' conceptual understanding in Mathematics. The overall mean of 3.46 indicated a high level, although the dimension scores showed that understanding was not equally developed. Relational reasoning received the highest mean of 3.72, followed by mathematical explanation at 3.66. These results suggest that learners were generally able to identify relationships among mathematical ideas and explain familiar concepts when adequate instructional guidance was available.

The weaker results occurred in application to unfamiliar tasks, with a mean of 3.27, and representational transfer, with the lowest mean of 3.19. The findings reveal a distinction between understanding a concept within a familiar classroom presentation and being able to reconstruct that understanding in another form or use it in a different problem. Learners appeared less consistent when required to translate a graph into an equation, connect

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a diagram with symbolic notation, or apply a known relationship to a problem structured differently from classroom examples. Liang and She (2023) found that multiple representational scaffolds supported stronger mathematical conceptual understanding and problem solving than reliance on a single representation. The present finding therefore suggests that the instructional concern lies not primarily in the absence of visual resources but in developing learners' capacity to move meaningfully among them.

Table 3. *Permutation-Based Multiple Regression Predicting Conceptual Understanding*

Predictor	B	SE	β	95% Bootstrap CI for B	Permutation *p*
Diagrammatic Representation	0.22	0.09	0.28	[0.04, 0.39]	.036
Graphical and Spatial Visualization	0.19	0.09	0.24	[0.01, 0.36]	.048
Visual Cueing	0.09	0.08	0.12	[-0.07, 0.24]	.267
Representation Linking	0.35	0.11	0.43	[0.13, 0.55]	.006

Model Statistic	Value
R^2	.610
Adjusted R^2	.548
F(4, 25)	9.78
Model permutation *p*	< .001
Number of permutations	10,000
Bootstrap resamples	5,000

Table 3 presents the permutation-based regression results examining the contribution of visual anchoring strategies to conceptual understanding. The full model explained **61.0% of the variance** in conceptual understanding, with an adjusted R^2 of .548. The overall model was statistically significant, $F(4, 25) = 9.78$, permutation $p < .001$, indicating that the visual anchoring dimensions collectively accounted for a substantial portion of differences in teachers' observations of learners' conceptual understanding.

Representation linking emerged as the strongest predictor, $\beta = .43$, $B = 0.35$, $p = .006$. Its 95% bootstrap confidence interval ranged from 0.13 to 0.55 and did not include zero. This result indicates that stronger instructional connections among diagrams, graphs, verbal explanations, and symbolic representations were associated with higher conceptual understanding. Diagrammatic representation also made a significant contribution, $\beta = .28$, $p = .036$, followed by graphical and spatial visualization, $\beta = .24$, $p = .048$.

Visual cueing did not independently predict conceptual understanding, $\beta = .12$, $p = .267$. Although teachers frequently used highlights, visual markers, positioning, and other cues, these practices alone did not explain meaningful differences in conceptual understanding once the other visual anchoring strategies were considered. The distinction suggests that directing attention toward information may assist learners in locating important details, but conceptual understanding requires learners to recognize relationships among representations. Gulkilik (2024) similarly found that support for representational fluency remained limited when opportunities to articulate invariant mathematical features and make connections across representations were insufficient.

The strongest statistical result is particularly important because representation linking was also the least practiced visual anchoring strategy in Table 1. Thus, the strategy with the greatest predictive contribution was the one teacher reported using least consistently. This discrepancy identifies a clear instructional priority for strengthening conceptual Mathematics teaching.

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Table 4. *Dominance Analysis of Visual Anchoring Strategies*

Predictor	General Dominance Weight	Share of Explained Variance	Rank
Representation Linking	.250	41.0%	1
Diagrammatic Representation	.150	24.6%	2
Graphical and Spatial Visualization	.130	21.3%	3
Visual Cueing	.080	13.1%	4
Total Explained Variance	.610	100.0%	

Table 4 presents the dominance analysis used to determine the relative contribution of each visual anchoring strategy across possible predictor combinations. Representation linking accounted for the largest share of explained variance at 41.0%, substantially exceeding the contribution of diagrammatic representation at 24.6%, graphical and spatial visualization at 21.3%, and visual cueing at 13.1%. The dominance results reinforced the regression findings and showed that representation linking retained the greatest explanatory importance even when the predictors were considered in different combinations.

The pattern provides a more specific understanding of visual anchoring in Mathematics. Merely increasing the quantity of visual materials may not produce the strongest conceptual gains. What appears more consequential is how teachers help learners connect a mathematical idea across visual, graphical, verbal, and symbolic forms. Multiple representations can support more sophisticated mathematical problem solving when learners are guided to coordinate the information contained in those representations rather than process each one separately (Liang & She, 2023).

Taken together, the results revealed an instructional mismatch. Teachers demonstrated strong use of diagrams, graphical displays, and visual cues, yet representation linking remained only moderate. Learners likewise showed stronger relational reasoning and explanation but weaker representational transfer and application to unfamiliar tasks. The regression and dominance analyses connected these two patterns by identifying representation linking as the strongest contributor to conceptual understanding. The central finding therefore suggests that the next instructional step is not simply to make Mathematics more visual, but to make the relationships among visual and symbolic forms more explicit. Such an approach may help learners move beyond recognizing mathematical information toward understanding, translating, and applying the ideas represented.

CONCLUSION

Visual anchoring strategies supported conceptual understanding in secondary Mathematics, but their effectiveness depended on how well teachers connected visual, graphical, verbal, and symbolic representations. Although diagrammatic representation, graphical visualization, and visual cueing were commonly practiced, representation linking emerged as the most influential predictor of conceptual understanding while remaining the least consistently used strategy. Learners also showed stronger relational reasoning and mathematical explanation than representational transfer and application to unfamiliar tasks, indicating that understanding weakened when mathematical ideas had to be expressed in a new form or applied beyond familiar examples. Based on these findings, Mathematics teachers are encouraged to give greater instructional attention to representation linking by explicitly guiding learners in translating diagrams into equations, graphs into verbal explanations, and symbolic forms into visual models. Professional development activities may likewise focus on designing lessons that integrate multiple representations in a connected and purposeful manner, while classroom assessments should include tasks that require learners to transfer concepts across representations and apply them to less familiar mathematical situations.

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