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Enhancing Students' van Hiele Geometric Thinking Levels Through the Integration of Geometer's Sketchpad (GSP) in Geometry Learning

Sugi Hartono [1*], Rezky Ramadhona [1], Sri Irawati [1], Diena Frentika [1], and Heru Tri Novi Rizki [1]

[1] Department of Mathematics Education, Pascasarjana, Universitas Negeri Surabaya, Surabaya 60231, Indonesia.

* **Corresponding author:** sugihartono@unesa.ac.id

ABSTRACT: Van Hiele's theory of geometric thinking describes a hierarchical progression through distinct levels, from basic visualization to advanced deductive reasoning. Students typically struggle to transition between these levels without appropriate instructional support. Dynamic geometry software, such as Geometer's Sketchpad (GSP), has been shown to facilitate this transition by providing interactive visualizations and exploratory learning experiences. By allowing students to manipulate geometric shapes and observe properties dynamically, GSP enhances conceptual understanding and promotes higher-order thinking. This study aims to analyze the development of students' geometric thinking levels on geometry topics based on Van Hiele's theory after instruction using Geometer's Sketchpad (GSP). The research employed a qualitative approach, involving three participants from Class VIIG of a junior high school in Mojokerto, Indonesia, representing high, medium, and low ability levels. Data were collected through a test consisting of three questions designed to assess students' geometric understanding across various indicators of Van Hiele's thinking levels, followed by in-depth interviews. The findings revealed that GSP-based learning was effective in enhancing students' geometric thinking. Subjects ST and SD demonstrated significant progress, with several indicators advancing from Level 0 (Visualization) to Level 2 (Informal Deduction). In contrast, subject SR exhibited limited improvement, with most indicators remaining at Level 1 (Analysis). These results highlight GSP's potential to support students in developing a deeper understanding of geometric concepts. This study provides valuable insights for designing learning strategies tailored to the diverse needs and abilities of students, aiming to facilitate higher levels of geometric thinking.

Keywords: van hiele's thinking levels, geometer's sketchpad (GSP), geometry.

I. INTRODUCTION

Geometry plays a crucial role in mathematics education as it helps students develop spatial reasoning, logical thinking, and problem-solving skills [1,2]. It encompasses fundamental concepts such as lines, planes, and spatial relationships that are introduced from an early stage in schooling [3]. However, despite its importance, numerous studies indicate that students continue to struggle with geometry learning [4, 5]. Research by Khusna et al. [6] highlights the low achievement levels of elementary school students in geometry, while studies by Birgin and Ozkan [7] reveal that junior high school students frequently make errors in understanding geometric relationships, such as classifying rhombuses as non-parallelograms. At the high school level, Nuraeni et al. [8] report that students' performance in geometry is often weaker compared to other areas of mathematics. These persistent challenges highlight the need for more effective instructional approaches to enhance students' understanding of geometric concepts.

One widely recognized framework for improving geometry learning is Van Hiele's theory, which describes five hierarchical levels of geometric thinking: visualization, analysis, abstraction, deduction, and rigor [9, 10].

According to this theory, students must progress through each level sequentially to develop a deeper understanding of geometric concepts. However, studies indicate that many students remain at lower Van Hiele levels, limiting their ability to engage in higher-order geometric reasoning. Research by Clements and Battista [11] found that students often struggle to progress beyond the visualization level due to inadequate learning experiences that support higher-level thinking. In Indonesia, research by Sugiarto and Hidayah [12] showed that many Indonesian students remain at Van Hiele level 0 (visualization) and level 1 (analysis), indicating difficulties in abstract reasoning and logical deduction in geometry. Furthermore, a study by Fathoni et al. [13] revealed that Indonesian students often rely on rote memorization rather than conceptual understanding when solving geometry problems, which hinders their ability to advance through the Van Hiele levels.

Despite the recognized importance of supporting students' transition through Van Hiele levels, most instructional approaches in Indonesian classrooms still rely on traditional teaching methods that lack dynamic and interactive components [14]. While digital tools such as GeoGebra and Cabri Geometry have been introduced in various contexts, there is limited research focusing specifically on how Geometer's Sketchpad (GSP) can be used as a pedagogical intervention aligned with Van Hiele's learning phases. In particular, the potential of GSP to facilitate students' progression between geometric thinking levels by engaging them in visual, exploratory, and deductive reasoning has not been thoroughly investigated, especially in qualitative classroom settings.

To address this gap, this study aims to investigate how Van Hiele-based learning using Geometer's Sketchpad facilitates students' progression through the levels of geometric thinking. The research objectives are: (1) to examine changes in students' Van Hiele levels before and after GSP-assisted instruction, (2) to explore the cognitive processes that occur during learning with GSP across students of different ability levels, and (3) to evaluate the relative effectiveness of GSP compared to conventional teaching and other digital tools.

By aligning these objectives directly with the identified research gap, this study offers both theoretical and practical contributions: it provides empirical insight into how GSP facilitates level transitions in the Van Hiele model, and proposes an instructional framework that supports cognitive development through structured digital exploration. The findings are expected to inform more effective instructional design in geometry education and offer recommendations for teacher professional development focused on technology integration and cognitive scaffolding.

II. LITERATURE REVIEW

The Van Hiele theory was developed by Pierre van Hiele and Dina van Hiele-Geldof in 1960 to explain the stages of children's understanding of geometric concepts [15]. This theory states that children's understanding of geometry develops through specific hierarchical levels. Additionally, this theory emphasizes the importance of learning activities that help students transition from one level of understanding to the next [16].

The levels of understanding in the Van Hiele theory consist of five stages: (1) Visualization, where students recognize geometric shapes as a whole without paying attention to their specific characteristics or components; (2) Analysis, where students begin to observe and recognize the properties of geometric figures but cannot yet understand the relationships between these properties or between different geometric figures; (3) Abstraction, where students start to comprehend the relationships between geometric properties and can apply these concepts to problem-solving; (4) Deduction, where students understand definitions, axioms, and theorems in geometry and begin to construct and comprehend formal proofs; and (5) Rigor, where students can engage in formal reasoning within mathematical systems, including geometric systems, and can accept valid proofs even if they contradict intuition or empirical perception [17]. Research conducted by Burger and Shaughnessy [18] produced indicators of geometric thinking development based on the Van Hiele theory. However, their study only provided indicators for levels 0 through 3 in students' geometric thinking development.

To improve a stage of thinking to a higher stage of thinking, van Hiele proposed learning that involves 5 phases (steps), namely: information, directed orientation, explication, free orientation, and integration [19, 20].

- Phase 1: Information, at the beginning of this phase, the teacher and students conduct a Q&A so that the initial concepts about the material to be studied can be conveyed. The teacher presents new information in each question that is designed as carefully as possible so that students can relate the initial concepts to the material to be studied. The form of the question is directed at the concepts that students already have, for example what is a line of equal length, what is a congruent angle, and so on.
- Phase 2: Directed orientation, Students explore the topics studied through tools that have been carefully prepared by the teacher. This activity will gradually reveal to students the structures that characterize this stage of thinking. So, tools or materials are designed into short tasks so that they can elicit specific responses.

- Phase3: Explication, based on previous experiences, students express their emerging views on the observed structure. In addition, to help students use appropriate and accurate language, teachers provide minimal assistance. This continues until the relationship system at this stage of thinking begins to appear real.
- Phase 4: Free orientation, Students face more complex tasks in the form of tasks that require many steps, tasks that are completed in many ways, and open-ended tasks. They gain experience in finding their own way, as well as in completing tasks. Through orientation among students in the field of investigation, many relationships between the objects studied become clear.
- Phase 5: Integration, Students review and summarize what they have learned. The teacher can assist in this synthesis by completing a global survey of what students have learned. This is important, but this summary does not reveal anything new.
- Geometer's Sketchpad (GSP) is a software tool designed to enhance the teaching and learning of geometry [21]. This software facilitates students' understanding of geometric concepts, ranging from basic elements such as points, lines, and angles to more complex ideas such as curves, rotations, and transformations [22, 23]. Through interactive animations, GSP enables students to visualize relationships between geometric elements, making abstract concepts more concrete and comprehensible.

According to the Van Hiele theory, students progress through hierarchical levels of geometric thinking, and GSP can serve as a valuable tool to support this development. At the visualization level, GSP allows students to explore and manipulate geometric shapes dynamically, helping them recognize figures in various orientations. At the analysis level, students can use GSP to investigate properties of geometric figures by measuring angles, side lengths, and relationships between elements. At the abstraction level, GSP supports students in identifying patterns and making generalizations about geometric relationships. Furthermore, at the deduction level, the software provides opportunities for students to experiment with conjectures, test hypotheses, and engage in geometric proofs with dynamic visual support.

Recent studies have highlighted the advantages of GSP in fostering visual and deductive reasoning in geometry [24, 25]. These studies suggest that GSP can improve students' engagement and understanding by offering interactive, exploratory environments. Such findings support the growing view that GSP is not only a visualization tool, but also an effective platform for structured pedagogy and cognitive development. Hartono [1] highlights several key features of GSP that contribute to these cognitive advancements, including:

a. High accuracy in digital construction and measurement, ensuring precise geometric representations.
b. Effective visualization of geometric figures in multiple dimensions, aiding conceptual clarity.
c. Support for inquiry-based learning, allowing students to conduct investigations, explorations, and problem-solving activities.
d. Enhanced reasoning and proof development, fostering students' confidence in making mathematical conclusions.
e. Dynamic features, such as animated transformations, trace functions, and simulation tools, which promote interactive learning.

By integrating GSP into geometry instruction, students are provided with a structured yet exploratory learning environment that aligns with the progression of Van Hiele's geometric thinking levels. This integration strengthens students' spatial reasoning, analytical skills, and deductive reasoning, ultimately supporting their overall mathematical development.

III. METHOD

This study employed a qualitative research approach to analyze students' geometric thinking development based on Van Hiele's theory after instruction using Geometer's Sketchpad (GSP). A qualitative approach was chosen because it allows for an in-depth exploration of the characteristics of students' thought processes as they progress through the Van Hiele levels. The study used a case study design, focusing on a small number of participants to gain detailed insights into how students engage with geometry concepts through GSP-based learning.

The methodological framework of this study consisted of four interconnected phases. First, participant selection was carried out using purposive sampling, targeting students with diverse mathematical abilities based on academic performance and communication skills. Second, during the pre-instruction assessment phase, participants completed a Van Hiele Geometric Thinking Test and participated in interviews to determine their initial level of geometric thinking and reasoning strategies. Third, the GSP-based learning intervention involved three instructional sessions designed in accordance with Van Hiele's five instructional phases: Inquiry, Guided Orientation, Explicitation, Free Orientation, and Integration. Finally, in the post-instruction assessment and analysis phase, participants took a post-test and engaged in follow-up interviews to identify changes in their geometric thinking. All data were analyzed thematically and triangulated with observational notes to ensure validity and trustworthiness.

1. PARTICIPANT

The participants of this study were three students from Class VIIG at a junior high school in Mojokerto, East Java, Indonesia. A purposive sampling technique was employed to select participants who represented a range of mathematical ability levels: ST (high-ability), SD (medium-ability), and SR (low-ability). The selection criteria included prior mathematics report card grades, teacher recommendations, and observed communication skills to ensure participants could effectively articulate their reasoning during interviews. This sampling method was intentionally chosen to support the exploratory qualitative design of the study, which prioritizes in-depth analysis of individual cognitive processes over generalizability.

The small sample size is justified by the study's qualitative nature, which seeks to examine students' geometric thinking development in detail rather than to generalize to a broader population. In this context, rich, descriptive data from a few carefully selected participants can yield valuable insights into how learners at different Van Hiele levels interact with dynamic geometry software. The selected class was heterogeneous, comprising students with diverse cognitive abilities, making it a suitable microcosm of the broader population and allowing for nuanced understanding of how GSP influences learners across ability levels.

2. DATA COLLECTION

The data collection process involved multiple instruments to ensure a comprehensive analysis of students' geometric thinking:

1.1 Van Hiele Geometric Thinking Test

- A pre-test was administered before instruction to determine each student's initial Van Hiele level.
- A post-test was conducted after GSP-based learning to assess changes in students' geometric thinking.
- The test consisted of three questions, designed based on Van Hiele's levels of geometric thinking indicators (visualization, analysis, abstraction, deduction, and rigor).
- The questions assessed students' abilities to recognize, classify, and reason about geometric properties and relationships.
- The test instrument was developed by adapting items from the validated Van Hiele test by Usiskin [26] to ensure alignment with the theoretical indicators. Expert review was conducted to confirm content validity and appropriateness for the target group.

1.2 Interviews

- Semi-structured interviews were conducted after the pre-test and post-test to explore students' reasoning behind their answers.
- Interview questions focused on: how students approached each problem; the reasoning behind their answers; their understanding of geometric relationships; and the role of GSP in helping them grasp the concepts.
- Interviews were recorded using an audio recorder and transcribed for analysis.
- The interview protocol was adapted from Usiskin's validated instrument and supplemented with GSP-based tasks to probe students' dynamic reasoning processes. Member checking was employed by allowing participants to review and confirm the accuracy of their responses and interpretations, enhancing the credibility of the findings.

1.3 GSP-Based Learning Activities

- Students participated in three instructional sessions using Geometer's Sketchpad (GSP), designed following Van Hiele's instructional phases (Inquiry, Guided Orientation, Explicitation, Free Orientation, and Integration).
- Specific GSP tasks included: constructing geometric figures (triangles, quadrilaterals, and circles); exploring geometric properties (e.g., measuring angles and side lengths dynamically); manipulating shapes to observe invariants and transformations (e.g., resizing a triangle while maintaining proportionality); and testing conjectures by adjusting figures and observing real-time changes.

These tasks were designed to facilitate students' transitions between Van Hiele levels, particularly from visualization (Level 0) to informal deduction (Level 2). Although this study employed a range of data collection instruments including the Van Hiele geometric thinking test, semi-structured interviews, and GSP-based learning activities to capture a comprehensive view of students' geometric reasoning, each tool presents specific limitations that warrant critical analysis. The Van Hiele test, consisting of three open-ended questions, provided a general measure of students' thinking levels but lacked the depth to reveal the nuanced cognitive transitions between levels, especially in a technology-supported learning context. Its static nature limits the ability to assess the dynamic visual reasoning processes that occur during GSP-based exploration. The semi-structured interviews, validated Van Hiele test and supplemented with GSP-based prompts, offered deeper insight into students' thought processes but relied heavily on verbal articulation, which may not fully represent students' internal reasoning. While GSP-based activities facilitated visual and interactive exploration aligned with Van Hiele phases, a key limitation is that the current version of GSP lacks automated tracking features such as activity logs, screen recordings, or process analytics that could objectively capture the learning process in real-time. Therefore, there is a pressing need for a new or enhanced GSP-based assessment tool that not only supports dynamic exploration but also integrates features to record, analyze, and evaluate students' cognitive development more accurately and comprehensively.

3. DATA ANALYSIS

The data in this study were analyzed using descriptive qualitative methods to explore students' geometric thinking development according to Van Hiele's theory after learning with Geometer's Sketchpad (GSP). Analysis began with a pre-test to determine each participant's initial Van Hiele level, followed by observation during GSP-based instruction and a post-test to evaluate progression. Semi-structured interviews were transcribed and analyzed to gain deeper insights into students' cognitive processes. Interview responses were subjected to thematic coding, where recurring patterns were identified and categorized into key themes such as visual reasoning, relational understanding, and deductive argumentation. Coding was conducted independently by two researchers to ensure consistency and reliability. Discrepancies were resolved through discussion until consensus was reached. Representative quotes were selected to support the interpretation of each theme and to illustrate students' reasoning and conceptual development in their own words. This approach enabled the researchers to contextualize quantitative gains within the lived experiences and thought processes of the participants. To ensure the credibility and trustworthiness of the findings, data triangulation was employed by cross-referencing results from tests, interviews, and classroom observations. The validity of the test instruments was supported by adapting Usiskin's [26] validated Van Hiele assessment and confirming content alignment through expert judgment. Inter-rater reliability was strengthened through independent coding of student responses by a second mathematics educator. Furthermore, to address potential bias in interpreting interview data, coding was independently conducted by two researchers, and any discrepancies were resolved through discussion until consensus was achieved. Additional strategies such as peer debriefing and ongoing reflection helped ensure that interpretations remained grounded in the data and not influenced by researcher expectations.

IV. RESULTS AND DISCUSSION

The findings of this study provide evidence of the effectiveness of Van Hiele-based instruction using Geometer's Sketchpad (GSP) in fostering students' geometric thinking. The results are presented in alignment with the research objectives, which sought to examine how GSP-assisted learning supports the development of students' Van Hiele levels and cognitive processes. To ensure a logical structure, the analysis is organized by comparing students' initial understanding captured through the pre-test and pre-interview with their post-intervention outcomes captured through the post-test and post-interview.

Before the GSP-based instruction, all three participants ST (high-ability), SD (medium-ability), and SR (low-ability) were classified at Van Hiele Level 0 (Visualization). At this stage, their understanding of geometric concepts was limited to identifying shapes based on visual appearance, without reference to properties or relationships. They were unable to articulate reasoning related to angles, parallelism, congruence, or other analytical features, indicating a surface-level understanding.

Following the intervention, notable progression was observed. Subject ST demonstrated significant development, advancing to Level 2 (Informal Deduction), as evidenced by their ability to analyze properties, justify relationships, and construct informal logical arguments. Subject SD also progressed from Level 0 to Level 2, showing improvement in reasoning, particularly in making generalizations and explaining geometric invariants. Meanwhile, subject SR improved from Level 0 to Level 1 (Analysis), demonstrating an increased capacity to identify and describe properties of shapes, although still lacking the ability to justify reasoning or draw conclusions beyond descriptive analysis (Figure 1).

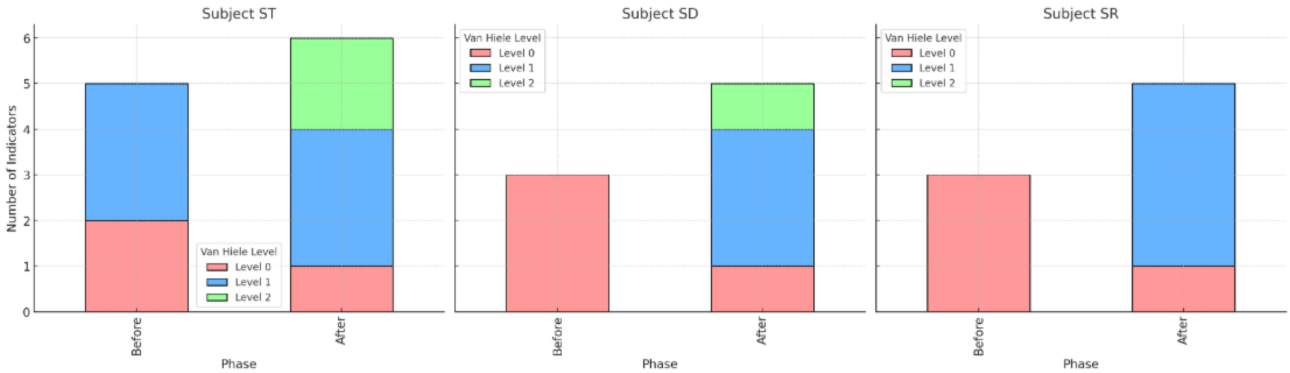

FIGURE 1. Van hiele level progression before and after GSP-based instruction.

These findings align with the study's purpose of exploring cognitive growth across ability levels and confirm that structured, phase-based GSP instruction can facilitate students' progression through the Van Hiele hierarchy. The following sections provide detailed analysis for each subject, starting with ST. The development of ST's geometric thinking in response to each test item is summarized in the table below.

Table 1. Van hiele's geometric thinking subject ST.

	Before Learning Geometer Sketchpad			After Learning Geometer Sketchpad		
		Indicator			Indicator	
No. Problems	Level 0	Level 1	Level 2	Level 0	Level 1	Level 2
1	-	a and b	-	-	a	e
2	b	a	-	b	a	-
3	-	c	-	-	a	e

As Indicated by the data above, subject ST can choose quadrilateral shapes according to their properties but the subject still ignores class inclusion among the shapes. This can be seen in the answers to indicators a and b level 1 question no. 1. Then the subject also uses the properties of rectangles and squares in choosing objects in the shape of the shape. The subject still relies on visual examples in determining the flat shapes in question no. 2. Furthermore, in indicator c level 1 question no. 3, the subject can choose a qua drilateral shape based on one certain similarity of properties and ignores other properties.

From the table above and the interview results, the subjects used the properties in selecting quadrilaterals, although some were incomplete in mentioning them. The subjects also understood the existence of class inclusion between quadrilaterals. This can be seen in examples of student response and the interview excerpt on question no. 1 as follows.

The interview is:

- Researcher: "What is your reason for choosing shapes 3 and 10 as squares?"
- ST: "Because the shapes 3 and 10 include the properties of a square."
- Researcher: "What are some examples?"
- ST: "The sides are the same length and the angles are 900."
- Researcher: "What is your reason for choosing shapes 2, 4, 14, 3, 6, 8, 9, 10, 7, and 11 as parallelograms?"
- ST : "Because the properties of a parallelogram are present in shapes 2, 4, 14, 3, 6, 8, 9, 10, 7, and 11."
- Researcher: "what are the buildings?"
- ST: "Rectangle, square, rhombus are all parallelograms."

The subject still relies on surrounding objects in determining the flat quadrilateral shapes. This can be seen from the interview excerpt for question no. 2 as follows.

- Researcher: "Why did you choose asbestos roof as a square shaped object?"
- ST: "Because asbestos roofs have square properties."
- Researcher: "What are some examples?"
- ST: "It has the property that the angles are 900 and the diagonals are the same."
- ....
- Researcher: "Why didn't you mention objects shaped like parallelograms, rhombuses, kites and trapezoids?"

- ST: "Because in the room there are no objects in the shape of parallelograms,
- rhombuses, kites, and trapezoids."

The subject can also mention the class inclusion of squares with rectangles. This can be seen in the following interview excerpt no. 3.

- Researcher: "Why do you call shapes 3 and 1 rectangles?"
- ST: "Because the properties of the 3 and 1 shapes are properties that are possessed by rectangles."
- Researcher: "For example?"
- ST: "It has a 900 angle and the diagonals are the same."
- Researcher: "Even though I saw building no. 1 was a square, you chose building no. 1? So the square is a rectangle, right?"
- ST: 'Yes."

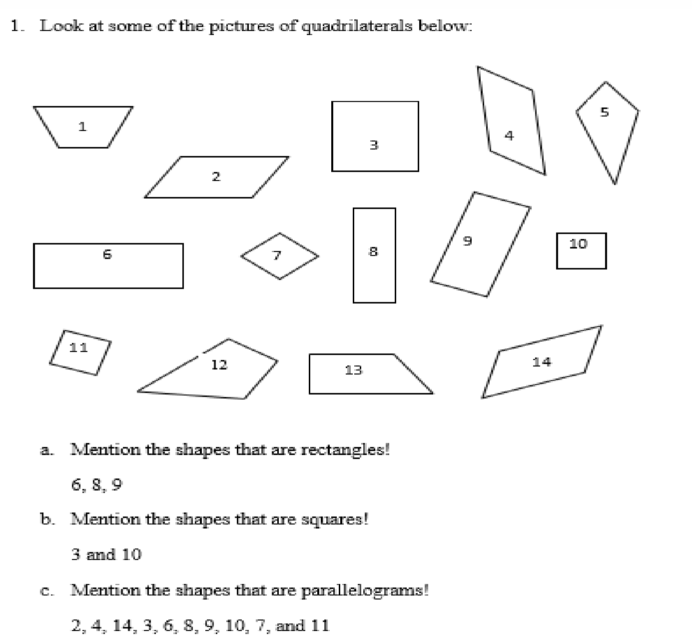

FIGURE 2. Examples of student ST response

The description above show that it was found that the van Hiele geometric thinking of subject ST before learning using GSP showed in question 1: indicators a, b at level 1, for question 2: indicator b level 0, a level 1 and question 3: indicator c level 1. And the subject's van Hiele thinking changed after learning using GSP to question 1: indicator a level 1, e level 2, question 2: indicator b level 0, a level 1, and question 3: indicator a level 1, e level 2. So it can be concluded that the van Hiele geometric thinking of subject ST changed, especially for questions 1 and 3 which were initially level 1 then changed to levels 1 and 2. Next, to think about van Hiele geometry of subject SD in each question can be seen in the following table.

Table 2. Geometric thinking van hiele of subject SD.

	Before Learning Geometer Sketchpad			After Learning Geometer Sketchpad		
	Indicator			Indicator		
No. Problems	Level 0	Level 1	Level 2	Level 0	Level 1	Level 2
1	a	-	-	-	a	-
2	b	-	-	b	a	-
3	e	-	-	-	a	e

From the table 2, elementary school subjects are less precise in choosing a square shape. This can be seen in indicator a level 0 answer to question no. 1. Then the subject still relies on visual examples in determining flat shapes in question no. 2. Next, in indicator e level 0, question no. 3, the subject chooses shapes irregularly and inappropriately, this can be seen from answer no. 3, namely the shapes that are considered squares, are 1 and 4. Even though shape 4 is a rhombus and a rhombus is not a square.

As Indicated by the table above and the interview results, the subjects have been able to choose a shape using the properties of the shape, although there are some who are not quite right in mentioning the properties of a kite, namely that the angles are right angles and exactly parallel. This can be seen in examples of student response and the interview excerpt on question no. 1 as follows.

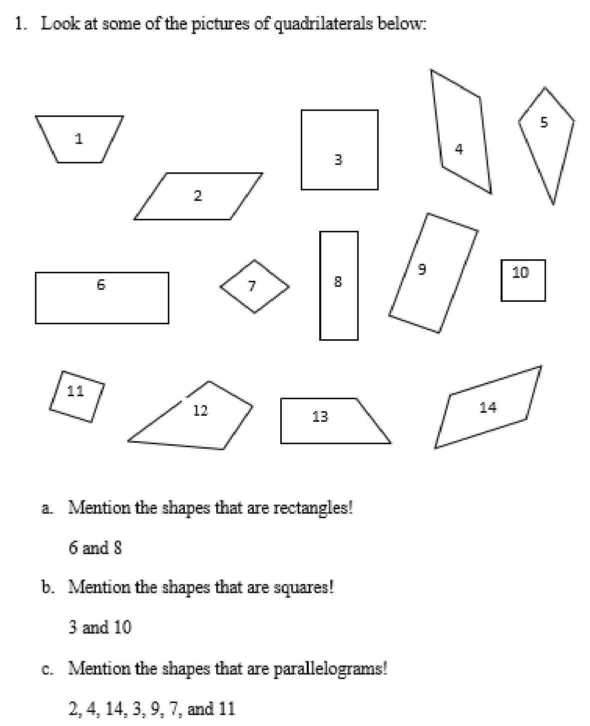

FIGURE 3. Examples of student SD response.

The interview is:

- Researcher : "What is your reason for choosing the shapes 10 and 3 as squares?"
- SD : "Because all sides are the same length."
- Researcher : "Is there anything else?"
- SD : "Both diagonals are the same length."

The subject still relies on surrounding objects in determining the flat quadrilateral shapes. This can be seen from the interview excerpt for question no. 2 as follows.

- Researcher : "Why didn't you mention objects shaped like parallelograms, rhombuses, kites and trapezoids?"
- SD : "Because there is no such thing in this room."

The subject can also mention the class inclusion of a square with a rectangle. Likewise, a rhombus with a square. This can be seen in the following interview excerpt no. 3.

- Researcher : "You know, number 1 here is a square, right?"
- SD : "Yes."
- Researcher : "Does that mean a square is a rectangle?"
- SD : "Yes."
- …………
- Researcher : "no.3, what is the shape?
- SD : "it is square."
- Researcher : "That means a square is a rhombus, right?"
- SD : "yes."

This result was found that the van Hiele geometric thinking of subject SD before learning using GSP showed in question 1: indicator a at level 0, for question 2: indicator b level 0 and question 3: indicator e level 0. The subject's van Hiele thinking changed after learning using GSP to question 1: indicator a level 1, question 2: indicator b level 0, a level 1, and question 3: indicator a level 1, e level 2. Thus, it can be concluded that the van Hiele geometric thinking of subject SD changed, which was initially level 0 for all questions then changed to levels 1 and 2. Furthermore, to think about van Hiele geometry of subject SR in each question is seen in the following table.

Table 3. Van Hiele's geometric thinking subject sr

	Before Learning Geometer Sketchpad			**After Learning Geometer Sketchpad**		
	Indicator			Indicator		
No. prob-lems	Level 0	Level 1	Level 2	Level 0	Level 1	Level 2
1	a	-	-	-	a and c	-
2	b	-	-	b	a	-
3	e	-	-	e	a	-

Based on the table 3, the subject is not quite right in choosing shape 4 as a kite shape. Whereas shape 4 is a parallelogram shape. This can be seen in indicator a level 0 answer to question no. 1. The subject relies on visual examples in determining flat shapes in indicator b level 0 question no. 2. Furthermore, in indicator e level 0 question no. 3, the subject makes a choice of a shape that does not match the properties he himself mentioned.

The subject has been able to choose a shape using the properties of the shape, although there are some who are not quite right in mentioning the properties of a rectangle, namely that the sides are not the same length. Then the subject is also still based on one similarity in choosing a rhombus shape. This can be seen in examples of student response and the interview excerpt on question no. 1 as follows.

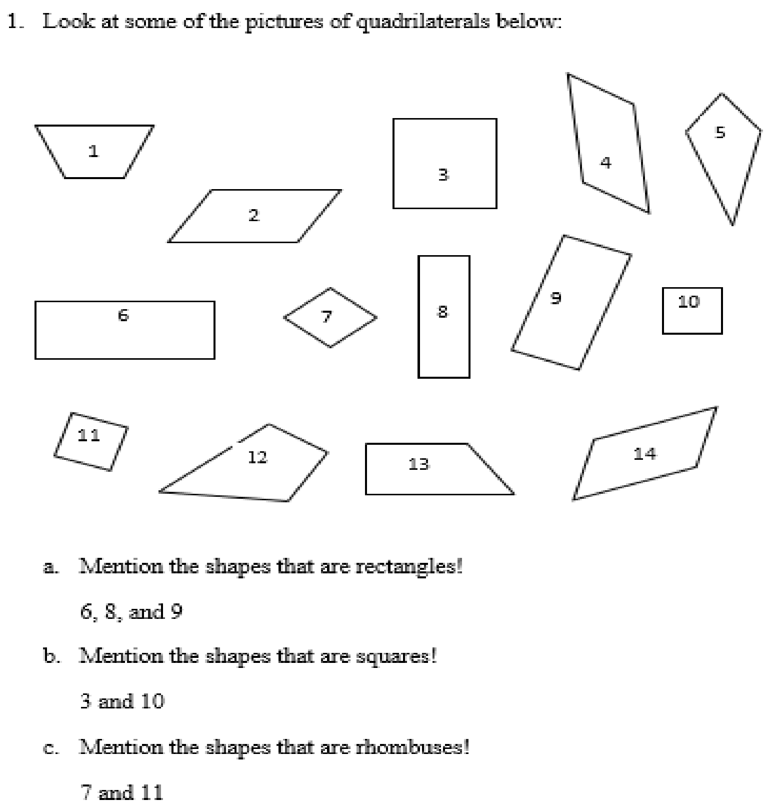

FIGURE 4. Examples of student SR response.

The interview is:

- Researcher: "What is your reason for choosing shapes 6, 8, and 9 as rectangles?"
- SR: "Because it has a right angle."
- Researcher: "Any other?"
- SR: "The sides are not the same length."
- ………..
- Researcher : "What is the reason you chose to get up 7, 11 including rhombuses?"
- SR: "Because a rhombus is the same as a square."
- Researcher : "His side."
- SR: "Yes, and the angles are not right angles."

The subject uses properties in naming rectangular and square objects. The subject also still relies on surrounding objects in determining quadrilateral flat shapes. This can be seen from the interview excerpt for question no. 2 as follows.

- Researcher: "Why do you call monitor, TV, and starvolt as square shaped objects?"
- SR: "Because its shape is the same as a square, that is, all four sides are the same length and the angles are right angles."
- ………….
- Researcher: "Why didn't you mention objects shaped like parallelograms, rhombuses, kites and trapezoids?"
- SR: "Because in that place there is no shape in question."

The subject made a building selection that did not match the characteristics he himself mentioned. This can be seen in the following interview excerpt no. 3.

- Researcher: "Why do you call shapes 1, 3, 4, and 5 squares?"
- SR: "Because it has sides of equal length and right angles."
- Researcher: "No. 5, is the angle a right angle?"
- SR: 'No, it is not.'
- Researcher: "what do you mean?"
- SR: "I wrote it wrong"
- Researcher: "So the only correct one is?"
- SR: "It is one."

Based on the previous description, it was observed that subject SR's van Hiele geometric thinking before using Geometer's Sketchpad (GSP) was at Level 0 across all questions: in Question 1, indicator a at Level 0; in Question 2, indicator b at Level 0; and in Question 3, indicator at Level 0. However, after learning with GSP, SR's geometric thinking showed improvement. In Question 1, SR progressed to Level 1 for indicators a and c. In Question 2, SR advanced from Level 0 to Level 1 for indicator a, while indicator b remained at Level 0. In Question 3, SR moved from Level 0 to Level 1 for indicator a, while indicator e remained at Level 0. This change indicates that SR's van Hiele geometric thinking shifted from Level 0 to Level 1 across the questions, showing initial development in geometric reasoning.

Data from the study also reveal varying levels of improvement among the three subjects: ST, SD, and SR, as detailed in Tables 1, 2, and 3. Subject ST exhibited substantial progress. Before learning with GSP, ST's thinking was primarily at Levels 0 and 1. After using GSP, ST showed significant advancement in several indicators. In Question 1, ST moved from Level 1 to Levels 1 and 2, demonstrating the ability to recognize geometric properties beyond basic visual cues. In Question 3, ST progressed from Level 1 to Levels 1 and 2, indicating the development of informal deduction skills and an understanding of the hierarchical relationships among quadrilaterals. This suggests that GSP helped ST develop a deeper understanding of geometric concepts.

Subject SD, initially at Level 0 across all questions, showed notable improvement after using GSP. In Question 3, SD advanced from Level 0 to Levels 1 and 2, indicating a shift from a visual approach to a more analytical one. In Question 2, SD moved from Level 0 to Level 1, reflecting a growing understanding of geometric properties beyond appearance. These improvements suggest that GSP successfully helped SD build a solid conceptual foundation for geometric reasoning. In contrast, subject SR demonstrated more limited progress. Before GSP learning, SR was at Level 0 across all questions. After using GSP, SR's thinking in Question 1 shifted from Level 0 to Level 1, reflecting an emerging recognition of shape properties. However, in other questions, SR remained at Level 1 without advancing to Level 2. These results indicate that although SR developed some analytical skills, the transition to informal deduction was not fully achieved, suggesting the need for further instructional support.

The results of this study indicate that GSP-based learning contributes significantly to improving students' geometric thinking levels, particularly in facilitating the transition from Level 0 (visualization) to Level 1 (analysis) and Level 2 (informal deduction). According to Van Hiele's theory, visual exploration and manipulation of geometric objects are crucial for supporting students' cognitive development in geometry. The interactive and dynamic nature of GSP allows students to actively engage with geometric shapes—rotating, resizing, and transforming them in real time—which enhances their conceptual understanding through exploration and discovery rather than passive observation. This environment promotes deeper thinking by allowing learners to test conjectures, observe geometric relationships, and receive immediate visual feedback, all of which are essential processes in moving from concrete visual understanding to abstract analytical reasoning. In this way, the use of GSP aligns not only with Van Hiele's theoretical framework but also with the broader objective of this study: to utilize technology as a tool to foster higher-order geometric thinking across different student ability levels.

This finding is also in line with previous studies by Patsiomitou et al. [27] and Sun et al. [28], which showed that the use of GSP can help students understand geometric concepts more deeply through direct interaction with geometric objects, thereby accelerating the transition of understanding from visual to analytical. Furthermore, several studies on creative reasoning in geometry [29, 30] emphasize that dynamic, exploratory environments are essential for fostering mathematical creativity, which includes the ability to flexibly approach problems, form and test conjectures, and use multiple strategies. The GSP environment supports these aspects by enabling students to investigate and manipulate geometric objects freely, thus encouraging creative reasoning alongside conceptual development. Therefore, the improvement observed in students' Van Hiele levels in this study reflects not only a cognitive progression but also demonstrates how GSP facilitates the development of creative mathematical thinking—an area that has become increasingly emphasized in 21st-century education.

In this regard, this study contributes to the growing body of literature that connects technological tools with both cognitive and creative aspects of learning mathematics. It provides empirical support for the integration of dynamic geometry software as a medium that not only strengthens conceptual understanding but also nurtures creativity in problem solving. By bridging Van Hiele's theory with research on creative reasoning, this study offers a more comprehensive perspective on how technology can support diverse dimensions of mathematical thinking in the classroom.

However, despite the development, this study also found that the increase in students' thinking levels did not occur evenly in all subjects. ST and SD subjects showed more significant development, with several thinking indicators initially at Level 0 or Level 1 which then increased to Level 2, reflecting an increase in their ability to make informal deductions and understand geometric concepts more abstractly. In contrast, the SR subjects experienced more limited development, with most indicators still at Level 1, indicating that in addition to the use of GSP, the development of geometric thinking is also influenced by individual factors such as cognitive readiness, students' prior understanding, and the teaching strategies used. These results confirm that although technology such as GSP is an effective tool, its success is highly dependent on a teaching approach that takes into account individual differences. Therefore, in accordance with the objectives of this study, a more adaptive learning strategy is needed to help students with different levels of ability to achieve optimal geometric thinking development according to Van Hiele's theory [31].

Several findings in this study are also supported by previous research demonstrating the effectiveness of Geometer's Sketchpad (GSP) in enhancing students' understanding of geometry. Ibili [32] found that using dynamic software like GSP helps students develop a deeper understanding of geometric concepts through interactive exploration. Additionally, Michisi [33] stated that GSP allows students to see relationships between geometric shapes more clearly, accelerating their transition from Level 0 (visualization) to Level 1 (analysis) in Van Hiele's theory. Another study by Wilson [34] also showed that students who learned using GSP tended to be more active in developing hypotheses and conducting independent explorations, supporting their progression to Level 2 (informal deduction). These findings reinforce the results of this study, where ST and SD experienced significant improvements in their geometric thinking levels, while SR still faced challenges in reaching higher levels. Thus, this study further confirms that GSP is an effective tool in helping students develop geometric thinking skills in alignment with Van Hiele's theory, although instructional strategies must still be tailored to accommodate individual student characteristics.

The effectiveness of GSP can be further assessed by comparing it with traditional methods of instruction. Previous studies, such as those by Patsiomitou et al. [27] and Sun et al. [28], found that dynamic geometry software accelerates students' understanding of geometric concepts by offering interactive and visual representations. Compared to traditional methods, which often rely on static diagrams and memorization, GSP provides an engaging, hands-on learning experience. The data suggest that students using GSP progressed more rapidly through Van Hiele's levels, particularly in their ability to analyze properties and make informal deductions. However, as seen with SR, the benefits of GSP are not uniform, reinforcing the need for differentiated instruction.

A closer look at individual student responses highlights specific areas of progress. ST's reasoning ability improved significantly. Initially, ST struggled with class inclusion but later demonstrated an understanding that squares are a subset of rectangles. This was evident in responses to Questions 1 and 3, where ST correctly identified relationships between quadrilaterals. SD transitioned from a purely visual approach to recognizing properties. Before GSP, SD incorrectly identified a rhombus as a square. After GSP instruction, SD correctly classified shapes based on their defining properties, reflecting a more analytical understanding. SR, despite some progress, continued to rely on visual identification rather than property-based classification. This indicates that SR might need additional instructional support beyond GSP to fully develop geometric reasoning.

The findings confirm that GSP-based learning effectively enhances students' geometric thinking by facilitating the transition from visualization to analysis and informal deduction. Based on indicator of van Hiele level in this research, showing measurable progress across different levels of understanding. However, individual cognitive differences must be considered when implementing such tools. While ST and SD made substantial gains, SR's limited progress suggests that differentiated instructional strategies are necessary to ensure all students benefit optimally. Future studies should explore the integration of GSP with other pedagogical approaches, comparing its effectiveness with traditional methods and alternative educational tools to better support students with diverse learning needs.

V. CONCLUSION

The conclusion of the results of students' Van Hiele geometry thinking levels on this geometry topic shows that learning using GSP is effective in improving students' geometric thinking levels, with most subjects showing an increase from Level 0 (Visualization) to Level 1 (Analysis) and even reaching Level 2 (Informal Deduction) on some indicators. ST and SD subjects experienced more significant changes, with certain indicators that were previously at Level 0 or 1 moving to Level 2, and SR subjects showed an increase from Level 0 to Level 1. This shows that GSP can facilitate the development of better geometric thinking. Future research could involve direct experimental comparisons between GSP, GeoGebra, and traditional geometry instruction to quantify their respective impacts on students' Van Hiele level progression. Additionally, future research should consider a longitudinal study to assess whether the improvements in Van Hiele levels persist over time and how long-term engagement with GSP influences students' ability to retain geometric concepts. Future research could incorporate a control group to compare the results of GSP-based learning with conventional methods, providing a stronger basis for evaluating its impact.

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Author Contributions

Sugi Hartoono and his contributions is conceptualization, methodology and data collection; Rezky Ramadhona and her contributions is manuscript writing and data analysis; Sri Irawati and her contributions is interpretation of results, and manuscript editing; Diena Frentika and her contributions is analyzes research data that has been collected; Heru Tri Novi Rizki and his contributions is research data analysis and helps input research.

Conflicts of Interest

The authors declare no competing interests are still not.

Data Availability Statement

Data are available from the authors upon request.

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REFERENCES

1. Hartono, S. (**2020**). Effectiveness of Geometer's Sketchpad Learning in Two-Dimensional Shapes. *Mathematics Teaching Research Journal*, 12(3), 84-93.
2. Judijanto, L., Manu, C. M. A., Sitopu, J. W., Mangelep, N. O., & Hardiansyah, A. (**2024**). The Impact of Mathematics In Science And Technology Development. *International Journal of Teaching and Le*arning, 2(2), 451-458.
3. Darmayanti, R., Laila, A. R. N., Khan, S., Fitriyah, I. D., Bausir, U., Setio, A., & Usmiyatun, U. (**2023**). Students' Attitudes Towards Learning Mathematics:" Too Soft Attitudes-Very Difficult-Boring-In A Good Way". *Indonesian Journal of Learning and Educational Studies*, 1(1), 29-50.
4. Stylianides, G. J., Stylianides, A. J., & Moutsios-Rentzos, A. (**2024**). Proof and proving in school and university mathematics education research: a systematic review. *ZDM–Mathematics Education*, 56(1), 47-59.
5. Mukuka, A., & Alex, J. K. (**2024**). Student Teachers' Knowledge of School-level Geometry: Implications for Teaching and Learning. *European Journal of Educational Research*, 13(3).
6. Khusna, N., Widiyono, Y., & Khaq, M. (**2023**). Improving Activity and Learning Outcomes Through the Student Team Achievement Divisions Learning Model for Elementary School Students. *Pedagogik Journal of Islamic Elementary School*, 6(1), 39-50.
7. Birgin, O., & Özkan, K. (**2024**). Comparing the concept images and hierarchical classification skills of students at different educational levels regarding parallelograms: a cross-sectional study. *International Journal of Mathematical Education in Science and Technology*, 55(4), 850-882.
8. Nuraeni, Z., Simarmata, R. H., & Tarigan, A. H. Z. (**2024**). Develop of learning tools based on worked example of geometry materials to improve students' mathematical representations ability in junior high school. In *AIP Conference Proceedings* (Vol. 3052, No. 1). AIP Publishing.
9. Haqq, A. A., Suyitno, A., & Zaenuri, Z. (**2023**). The use of van Hiele theory as a theoretical framework for technology-assisted geometry learning. In *AIP Conference Proceedings* (Vol. 2614, No. 1). AIP Publishing.
10. Restrepo-Ochoa, J. F., Gualdrón-Pinto, E., & Ávila-Ascanio, L. F. (**2023**). Improving the learning of geometric proportionality using van Hiele's model, mathematical visualization, and GeoGebra. *EURASIA Journal of Mathematics, Science and Technology Education*, 19(9), em2324.
11. Gurmu, F., Tuge, C., & Hunde, A. B. (**2024**). Effects of GeoGebra-assisted instructional methods on students' conceptual understanding of geometry. *Cogent Education*, 11(1), 2379745.
12. Meng, C., C. (**2009**). Enhancing Students' Geometric Thinking Through Phase-Based Instruction Using Geometer's Skechpad: A Case Study, *Jurnal Pendidik dan Pendidikan*, 24, 89–107.
13. Leong, K. E. (**2013**). Impact of Geometer's Sketchpad on Students Achievement in Graph Functions. *Malaysian Online Journal of Educational Technology*, 1(2), 19-33.
14. Idris, N. (**2009**). The Impact of Using Geometers' Sketchpad on Malaysian Students' Achievement and Van Hiele Geometric Thinking: A case study in Malaya, *Journal of Mathematics Teacher Education*,2 (2), 94-107.
15. Presmeg, N. (**2020**). Visualization and learning in mathematics education. *Encyclopedia of mathematics education*, 900-904.
16. Naufal, M. A., Abdullah, A. H., Osman, S., Abu, M. S., & Ihsan, H. (**2021**). Reviewing the Van Hiele Model and the Application of Metacognition on Geometric Thinking. *International Journal of Evaluation and Research in Education*, 10(2), 597-605.
17. Yee, L., P. (**2007**). *Teaching Secondary School Mathematics a Resource Book*. Singapore: Mathematics and Mathematics Education National Institute of Education Nanyang Tehnoloogical University.
18. Burger, W. F., & Shaughnessy, J. M. (**1986**). Characterizing the van Hiele levels of development in geometry. *Journal for research in mathematics education*, 17(1), 31-48.
19. Abdullah, A. H., & Zakaria, E. (**2013**). Enhancing students' level of geometric thinking through van Hiele's phase-based learning. *Indian Journal of Science and Technology*, 6(5), 4432-4446.
20. Hodiyanto, H., & Santoso, D. (**2020**). How Geometer's Sketchpad (GSP) Develops Geometry Concept Understanding. *International Journal of Trends in Mathematics Education Research*, 3(1), 31-35.
21. Kotu, A., & Weldeyesus, K. M. (**2022**). Instructional use of Geometer's Sketchpad and students' geometry learning motivation and problem-solving ability. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(12).
22. Meng, C. C., & Sam, L. C. (2013). Enhancing primary pupils' geometric thinking through phase-based instruction using the geometer's sketchpad. *Asia Pacific Journal of Educators and Education*, 28, 33-51.
23. Uygun, T. (2020). An inquiry-based design research for teaching geometric transformations by developing mathematical practices in dynamic geometry environment. *Mathematics Education Research Journal*, 32(3), 523-549.
24. Li, H. L., & Zulnaidi, H. (2024). Effects of Geometer's Sketchpad on Algebraic Reasoning Competency amongst Students in Malaysia. *Edunesia: Jurnal Ilmiah Pendidikan*, 5(1), 488-499.

25. Kotu, A., & Weldeyesus, K. M. (2022). Instructional use of Geometer's Sketchpad and students geometry learning motivation and problem-solving ability. Eurasia Journal of Mathematics, Science and Technology Education, 18(12), em2201.
26. Usiskin, Z. (1982). *Van Hiele Levels and Achievement in Secondary School Geometry*. CDASSG Project.
27. Patsiomitou, S., Barkatsas, A., & Emvalotis, A. (2010). Secondary students'" dynamic reinvention of geometric proof" through the utilization of linking visual active representations. *Journal of Mathematics and Technology*, 5, 43-56.
28. Sun, Z., Smith, C., Gemmiti, A., & Zhang, G. (2024). Analysis of the Intention of Chinese High School Students to Study Abroad in the Post-Pandemic Era, Based on the Push-Pull Theory. In *Proceedings of the 3rd International Conference on Education, Language and Art* (ICELA 2023) (Vol. 831, p. 173). Springer Nature.
29. Leikin, R. (2009). Exploring mathematical creativity using multiple solution tasks. *Creativity in mathematics and the education of gifted students*, 9, 129-145.
30. Lithner, J. (2008). A research framework for creative and imitative reasoning. *Educational Studies in mathematics*, 67, 255-276.
31. Belbase, S. (2013). Beliefs about teaching geometric transformations with geometers' Sketchpad: A reflexive abstraction. *Journal of Education and Research*, 3(2).
32. İbili, E. (2019). The use of dynamic geometry software from a pedagogical perspective: current status and future prospects. *Journal of Computer and Education Research*, 7(14), 337-355.
33. Machisi, E. R. I. C. (2020). Van Hiele theory-based instruction, geometric proof competence and grade 11 students' reflections. *Unpublished doctoral dissertation].* University of South Africa.
34. Wilson, A. M. (2011). One teacher's experience with implementing Geometer's Sketchpad to promote student engagement. *Unpublished Master's Thesis*, The Evergreen State College, Olympia, Washington.