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The Complexity of High School Students' Semiotic Graphics in Solving Statistical Problems

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Abstract

The ability to represent data graphically is a crucial skill in learning statistics, yet it involves complex semiotic processes that are often influenced by students' cognitive styles. This study was conducted to explore the semiotic complexity of high school students' statistical graphs about their cognitive styles: field dependent (FD) and field independent (FI). Using a descriptive qualitative approach, four 12th-grade students were selected based on the Group Embedded Figures Test (GEFT) and a standardized mathematics ability test to ensure cognitive style categorization and equal academic level. Data were collected through a Semiotic Graph Complexity Test (TKSG) and semi-structured interviews focusing on four semiotic components: problems, actions, concepts, and properties.The findings show that students with FI cognitive styles demonstrated a higher level of semiotic complexity, reaching the "joint graphs" level, characterized by coherent integration of data, appropriate graph selection, and accurate symbolic interpretation. In contrast, FD students exhibited lower levels of complexity, often limited to literal and superficial representations. These results confirm that cognitive styles significantly affect students' abilities to transform statistical data into meaningful graphical representations. This study highlights the importance of differentiated instruction based on cognitive styles, suggesting explicit scaffolding for FD students and more explorative tasks for FI students to enhance graph comprehension and statistical literacy.

Keywords Field Dependent; Field Independent; Mathematics Education; Semiotic Complexity; Statistical Graphs.

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INTRODUCTION

Mathematics is an essential discipline and is taught at every level of education, from elementary school to university. However, the wide distribution of material does not guarantee students' understanding of mathematics, especially in terms of problem-solving and the ability to represent data meaningfully. The mathematics learning process in many schools remains procedural and repetitive, characterized by teachers dominating the classroom with examples without providing space for student exploration (Latuputty et al., 2024)his condition results in weak creativity, critical thinking, and student independence in understanding and solving mathematical problems.

Ideal mathematics learning should develop conceptual and procedural thinking skills through understanding basic mathematical objects, namely facts, concepts, operations and principles (Safari, Yusuf & Nurhida, 2024). These objects cannot be understood instantly or simply memorized; deep understanding requires active engagement in the thinking process through various forms of representation. Mathematical representations—such as formulas, graphs, tables, and other visualizations—not only reflect mathematical meaning but also serve as symbolic communication tools in the learning process (Presmeg, 2006).

In line with the current curriculum, namely the Independent Curriculum and recommendations from the National Council of Teachers of Mathematics (National Council of Teachers of Mathematics, 2000). Data representation skills are recognized as a key skill for students. In the context of statistics learning, presenting data through graphs is one concrete form of such representation. Graphs such as histograms, bar charts, or pie charts present information concisely and visually, making it easier to interpret (Curcio, 1987; Nugraha et al., 2023). However, graphic presentation not only requires technical skills, but also involves semiotic complexity, namely the interaction between language, symbols, concepts, and students' thought processes.

The semiotic complexity of graphic representation is closely related to how students understand the meaning of mathematical objects and transform abstract ideas into visual forms. This process involves representation, interpretation, and symbolic actions that are not linear, but rather dynamic and iterative (Presmeg, 2006). This level of complexity demands a high level of cognitive engagement, including the ability to interpret, select appropriate presentation formats, and convey information accurately. In practice, students' ability to represent graphs is significantly influenced by their cognitive style. Cognitive style is an individual's characteristic in processing information, which is divided into two main categories: field-dependent (FD) and field-independent (FI) (Witkin, 1981). Individuals with an FD learning style tend to be dependent on environmental context, while individuals with an FI learning style are more analytical and able to process information independently. Previous studies have found that students with an FI learning style tend to have higher achievement in mathematics, including in understanding statistical concepts (Afifah, 2022; Rahman, 2021). Research by (Nisa et al., 2024) also shows that students' difficulties in data representation are closely related to complex thinking activities and cognitive style tendencies.

Various previous studies have highlighted the relationship between cognitive style and mathematics learning achievement (Afifah, 2011; Rufi'i, 2011; Ngilawajan, 2019), and analyzed students' difficulties in understanding data representations, particularly histograms

(Saiman, 2017; Lee & Meletiou-Mavrotheris, 2003; Nisa et al., 2019). However, these studies generally separate the study of cognitive style and the semiotic complexity of graphs, or only emphasize the technical aspects of graph creation without examining the meaning-making process of students. However, according to Batanero and Arteaga (2010), the semiotic dimension in statistical representation plays a crucial role in revealing the quality of students' conceptual understanding and thought processes.

This study offers novelty by integrating cognitive style analysis (FD and FI) with a study of semiotic complexity in histogram representation. The focus is not only on the final graph produced by students, but also on the semiotic processes that occur starting from data interpretation, symbol selection, transformation of abstract ideas into visuals, to the mathematical communication that is formed. This approach allows the identification of different thinking patterns between FD and FI students in the context of statistics learning, which so far has not been widely revealed in depth in the literature. Thus, this study is expected to provide theoretical contributions to the study of mathematical semiotics and practical implications for learning strategies that take into account differences in students' cognitive styles.

RESEARCH METHODE

This study uses a descriptive qualitative approach that aims to describe the semiotic complexity of students' graphs in solving statistical problems based on field-dependent (FD) and field-independent (FI) cognitive styles. This approach was chosen because it is appropriate for revealing the thought processes and meanings contained in the graphic representations produced by students, as well as differences in the cognitive characteristics of each individual. The study was conducted at SMAN Purwoharjo in the odd semester of the 2024/2025 academic year, with the main data collection taking place on December 19–20, 2024. The research subjects consisted of four grade XII IPA 1 students selected by purposive sampling: two students with a field-dependent cognitive style and two students with a field-independent cognitive style. Subject selection was based on the results of the Group Embedded Figures Test (GEFT) to determine cognitive style categories, and the Mathematics Ability Test (TKM) to ensure that all subjects had equivalent mathematical abilities. Both instruments have been validated by experts in mathematics education and tested for readability to ensure clarity and suitability to student characteristics. The following shows a summary of the validation data by Mathematics Education experts.

Table 1. Summary of Instrument Validation Results by Experts

Validator	Average Score		
	TKM Instrument	**TKSG Instrument**	**Interview Guide Instrument**
Validator 1	3.45	3.50	3.65
Validator 2	3.65	3.70	3.55
Validator 3	3.50	3.80	3.70
Validator 4	3.70	3.75	3.65

Category description:

$1{,}00 \leq x < 1{,}50$: Invalid

$1{,}50 \leq x < 2{,}50$: Less Valid

$2{,}50 \leq x < 3{,}50$: Valid

$3{,}50 \leq x \leq 4{,}00$: Very Valid

Based on the average score obtained and referring to the category description above, it can be concluded that each instrument used in this study after being validated produced a very valid category and was ready to be used.

The GEFT used is a standard instrument developed by Witkin, consisting of 18 main questions that test students' perceptual abilities in recognizing hidden geometric shapes. Meanwhile, the TKM consists of five descriptive questions covering various mathematical topics, including statistics, and adapted from questions based on High Order Thinking Skills (HOTS).

The primary data were collected through two techniques: a written test and semi-structured interviews. The primary test used was the Semiotic Complexity of Graphs Test (TKSG), a contextual problem with five items designed to explore students' ability to construct statistical graphs based on four levels of semiotic complexity: representing only individual data, individual results, separate graphs, and joint graphs. Each problem represents a specific level of complexity, reflecting students' mathematical thinking processes from the initial stage to the highest level in understanding and presenting graphical data. To deepen understanding of students' answers, semi-structured interviews were conducted focused on four semiotic objects: problems, actions, concepts, and properties, based on the theory of Arteaga and Batanero.

The data analysis process was conducted through three stages: data reduction, data presentation, and conclusion drawing. Data reduction was carried out to filter relevant information from the results of the TKSG and interview transcripts. The reduced data were then presented in narrative and tabular form to identify answer patterns based on students' cognitive styles. Next, conclusions were drawn by interpreting the results of the graphical representation based on semiotic complexity indicators, accompanied by triangulation between test and interview results to increase the validity of the findings. This analysis procedure refers to the Miles and Huberman model and is linked to the semiotic theoretical framework of Peirce and Presmeg. With this procedure, this study seeks to uncover more deeply how the FD and FI cognitive styles influence students' ways of solving statistical problems, particularly in the process of constructing semiotically complex graphical representations.

RESULTS AND DISCUSSION

This study aims to describe and analyze the semiotic complexity of high school students' graphs in solving statistical problems, viewed from the perspective of field-dependent (FD) and field-independent (FI) cognitive styles. Based on the results of the graph semiotic complexity test (TKSG) and interviews, four main subjects were obtained: two FD-style students coded S1 and S2 and two FI-style students coded S3 and S4. These subjects were given the test shown in the following link https://drive.google.com/file/d/1-WcsFo-GdsT2opn25RBjMhRo3KkpOO72/view. The assessment is based on indicators of problems, actions, concepts, and properties that reflect the semiotic complexity of the graph, classified into four levels: Representing Only the Student Data, Representing Individual Results, Separate Graphs, and Joint Graphs.

The results of the work of students with the first dependent cognitive style, coded S1, are shown in Figure 1. Based on Figure 1 above, it is known that in answer to question number 1, the S1 student plotted blood type on the X-axis and frequency on the Y-axis without distinguishing the donor's gender, so the frequency used was the total for each blood type. Based on Tuesday's donor data, the subject connected the plotted points with a line. The resulting graph was incomplete because it was not accompanied by a title or directional arrows. In question number 2, the S1 student created a table with rows containing gender and columns containing blood type, then filled it with the frequency of each blood type according to gender. The S1 student created two bar graphs, each showing data on the blood types of male and female donors in the answer to question number 3. In both graphs, the X-axis contains the blood type and the Y-axis contains the frequency, based on the question. The graphs were colored, but the coloring was inconsistent and meaningless. The proportion of the bar height was not appropriate because the scale was not considered. Although they had included the X-axis, Y-axis, and bars with blood type labels, both graphs did not have titles. In answer to number 4, the S1 student created two line graphs, each presenting data on the blood types of male and female donors.

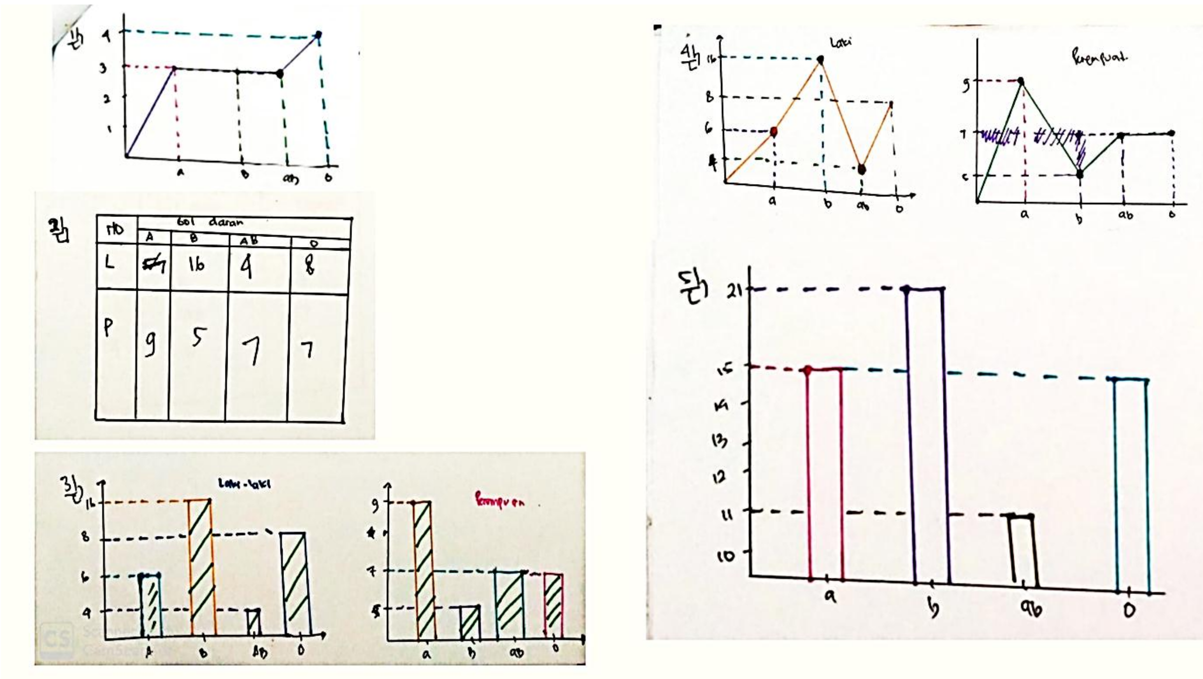

Figure 1. Results of TKSG Work by S1 students

In both graphs, the X-axis displays blood types A, B, AB, and O, while the Y-axis displays frequency. Students differentiate the line colors: orange for male donors and green for female donors. Although they plotted points according to the data and connected them with lines, they did not pay attention to the appropriateness of the scale so that the graphs were not proportional. The graph for male donors was marked with arrows on the axis, but the graph for female donors was not. In addition, both graphs were not equipped with titles so they were not completely complete. Answer to question number 5 An undergraduate student created a bar graph with the X-axis containing blood types and the Y-axis containing frequency. Four bars were created according to the high frequency of each blood type, but the frequency numbering started from 10 to 15 and then jumped to 21. The scale and proportionality of the graph were not considered so the results were not proportional. The graph was also incomplete because the X and Y axes did not have arrows, were not given a title, and did not include details of the day or gender of the donor.

The results of the work of students with the second filed dependent cognitive style, coded S2, are shown in Figure 2 below.

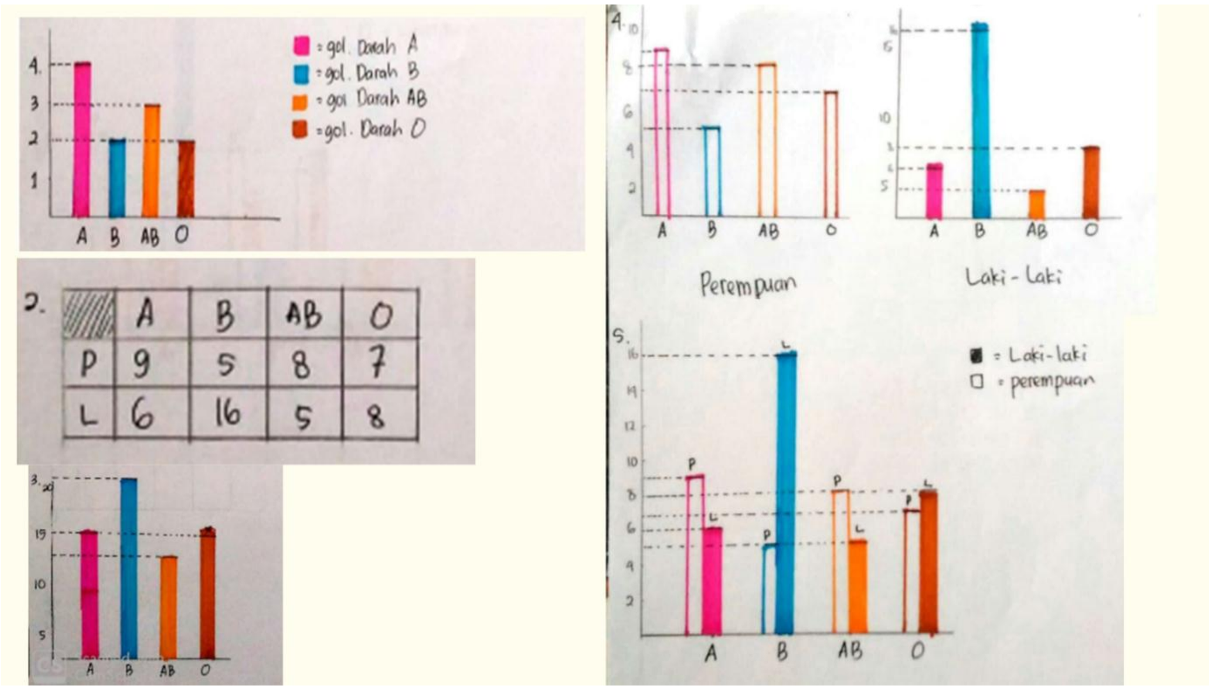

Figure 2 Results of TKSG Work S2 student

Based on Figure 2 above, it is known that Student S2 initially drew a bar graph with the X-axis containing the order of donors and the Y-axis containing gender, then revised it. In the revised result, the X-axis contains blood type and the Y-axis contains frequency, with different colors for each blood type: pink (A), blue (B), orange (AB), and brown (O). The student did not differentiate the donor's gender, but instead calculated the total frequency of each blood type. Friday's data was mapped to the graph proportionally because the scale and bar were taken into account. However, the graph is incomplete because the X- and Y-axes were not marked with arrows as markers for the infinite line. Student S2 created a table with rows containing gender and columns containing blood type, then filled it with the frequency of each blood type according to gender in answer number 2. In answer number 3, Student S2 created a bar graph that presents data based on blood type, with the X-axis containing blood type and the Y-axis containing frequency. Coloring was used to differentiate blood types: pink (A), blue (B), orange (AB), and brown (O). Although the frequency range was taken into account, the scale was not measured precisely so the height of the bar was disproportionate. The graph is quite complete because it contains the X axis, Y axis, bars, blood type labels, and gender identity, but is not equipped with arrows on the axes. Answer number 4 Student S2 created two bar graphs, each showing data on the blood types of female and male donors. The X axis contains the type of blood type, while the Y axis contains the frequency, based on the frequency distribution table in number 2. Coloring is used to differentiate blood types: pink (A), blue (B), orange (AB), and brown (O). In the graph for female donors, the bars are not fully colored, while in the male donors they are fully colored. The scale on both graphs is the same, with a range of 1, but the distance between the scale and the bars is not proportional. The graph already contains bars with blood type labels, but the X and Y axes are not marked with arrows and both graphs do not have titles. In the final answer Student S2 created one bar graph with the X axis containing the type of blood type and the Y axis containing the frequency. The graph consists of four bars with a height according to the number of each blood type, using a frequency scale with intervals of 2 from 2 to 16. The graph is proportional, but is not complete because the X and Y axes are not marked with arrows, do not have a title, and do not contain detailed data on the day and gender of the donor.

The results of the work of students with the first independent filed cognitive style, coded S3, are shown in Figure 3 below.

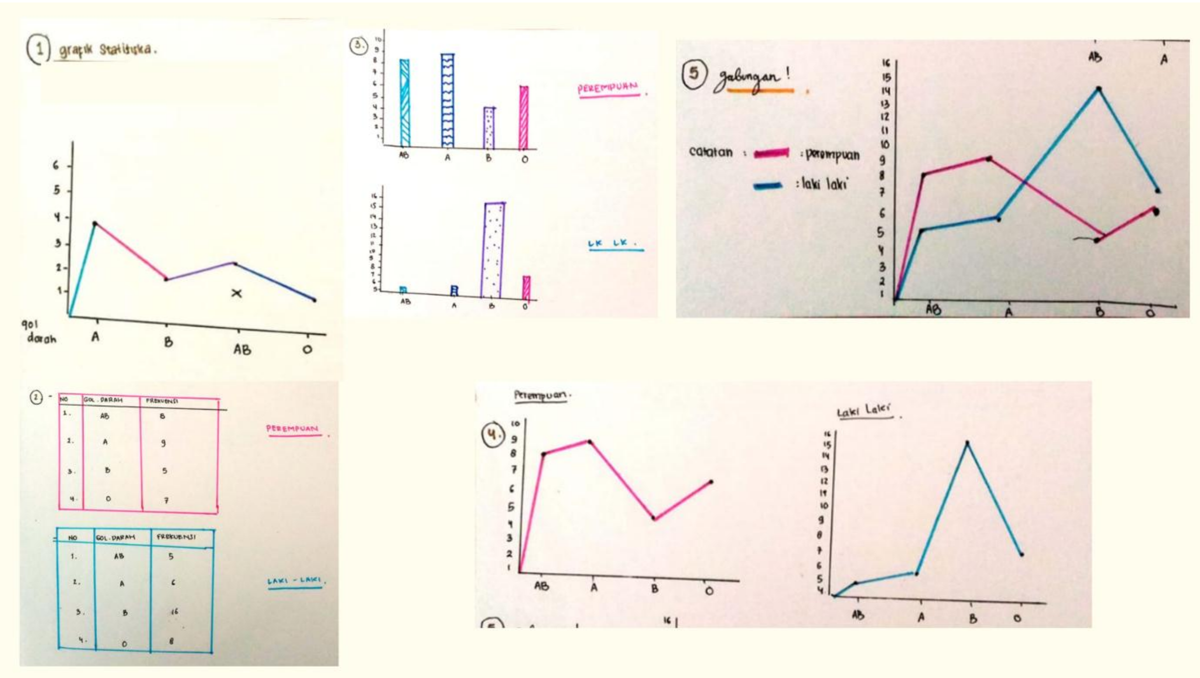

Figure 3 Results of TKSG Work by S3 students

Based on Figure 3 above, in answer number 1, the first step is to calculate the frequency of each blood type per day, then choose one day to create a line graph. Student S3 draws the X-axis containing the blood type and the Y-axis containing the frequency, without differentiating the donor's gender. The frequency points are connected with different colored lines for each segment. The graph is not proportional because the comparison of the frequency scale is not considered. The graph has been titled, but the X and Y axes are not equipped with arrows. In answer number 2, the student creates two frequency distribution tables, one each for female and male donors. Blood type is placed in the left column and frequency in the right column. The calculation is done for all days, with the only difference being the donor's gender. In answer number 3, the student creates two bar graphs, one each for female and male donors. Blood types are placed on the X-axis in the order AB, A, B, and O, while the Y-axis contains the frequency scale. In the female donor graph, the scale starts from number 1, while for male donors from number 5. Both graphs are created based on the previous frequency distribution table. Coloring is used to differentiate blood types: light blue (AB), dark blue (A), purple (B), and pink (O). Students do not maintain proportionality between the scale and the height of the bar due to the difference in the starting point of the scale, even though the scale range is the same, namely 1. The graph already contains the blood type identity on the bar and gender identity, but the X and Y axes are not equipped with arrows. Students create two line graphs, each depicting the number of blood bags from female donors and male donors. The X axis contains the type of blood type, while the Y axis contains the frequency. The graphs are made based on the previous frequency distribution table, with pink for female donors and blue for male donors. The frequency scale on the female graph starts at 1, while on the male graph starts at 4, both using a scale range of 1. The difference in the starting point of the scale causes the graph to be disproportionate. The graph already contains points representing blood types, blood type identities at each point, and gender identity, but the X and Y axes are not equipped with arrows. In the last question, the student creates a combined line graph from the graph in number 4, consisting of two pink lines for female donors and blue for male donors. The blood type is placed on the X-axis and the frequency on the Y-axis, with a frequency scale starting from 1 and a range of 1. The graph is not proportional because the distance between the ranges on the scale is not appropriate. The graph is incomplete because the X and Y axes do not have arrows, there is no graph identity, and it does not contain detailed data on day and gender.

The results of the work of students with the second independent filed cognitive style, coded S4, are shown in Figure 4 below.

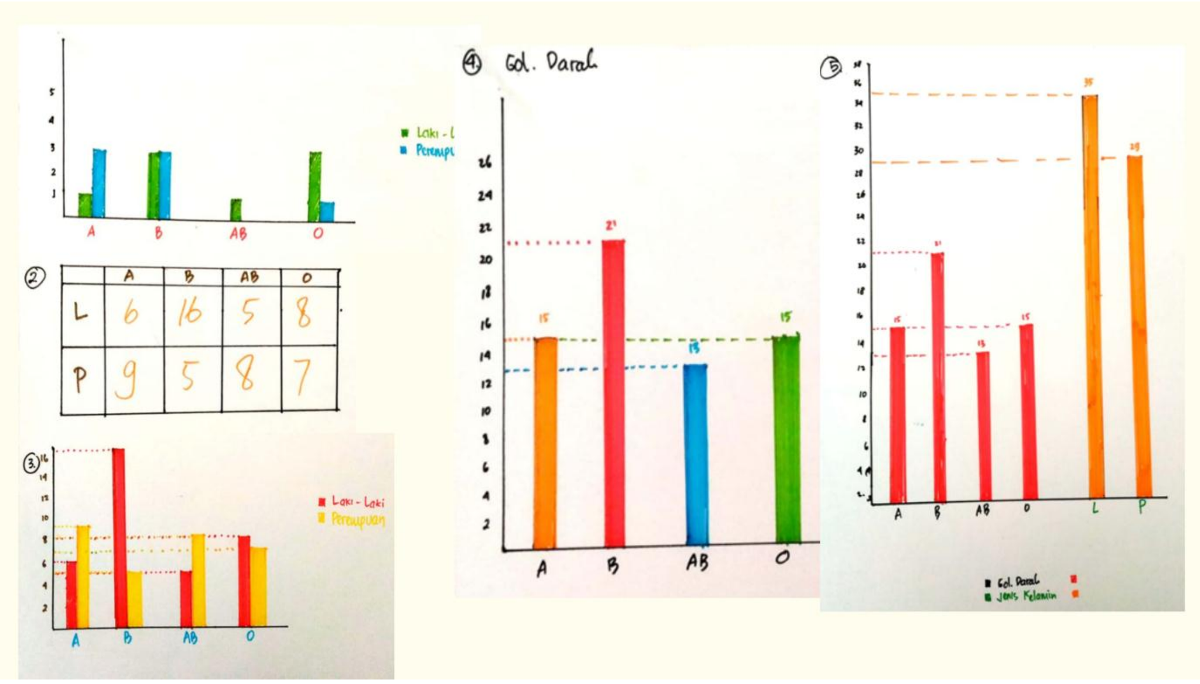

Figure 4 Results of TKSG Work by S4 students

Based on Figure 4 above, student S4's answer for number 1 begins with drawing a bar graph with blood type frequency data based on the day. The student calculates the frequency of each blood type, chooses one day (Monday), then places the blood type on the X-axis and the frequency on the Y-axis. Green is used for female donors and blue for male donors. The graph is made proportionally according to frequency, has been identified, but the X and Y axes are not equipped with arrows so the completeness is only sufficient. In answer number 2, the student creates two frequency distribution tables, one each for female donors and one for male donors. Gender is placed in the left column and blood type at the top of the table. Calculations are carried out for all days, with the only difference being based on gender. The student creates one bar graph representing male and female donors. Blood types are placed on the X-axis in the order A, B, AB, and O, while the frequency scale on the Y-axis uses a range of 2 starting from number 2. This graph is made based on the frequency distribution table. Coloring is used to differentiate gender, namely red for females and yellow for males. The resulting graph is quite proportional because the ratio between frequency and bar height has been considered. In terms of completeness, the graph already includes the identity of the blood type on each bar and the gender label, but the X and Y axes are not marked with arrows. Students created two bar graphs. The first graph displays the number of blood bags by blood type, while the second graph shows the number of donors by gender. In the first graph, the X axis contains blood type and the Y axis contains frequency, while in the second graph the X axis contains gender and the Y axis contains frequency. Both graphs were created based on the frequency distribution table in question number 2. The coloring in the first graph is orange for blood type A, red for B, light blue for AB, and green for O. In the second graph, blue represents male donors and green represents female donors. Students have paid attention to the appropriateness of the scale with frequency, but the resulting graph is still not proportional. The scale range used is 2 with the same starting point on both graphs. In terms of completeness, the graph already includes the identity of blood type or gender, but the X and Y axes are not marked with arrows. Student S4 created a combined bar graph from the graph in number 4. The bars on the graph are colored differently: red for blood type and orange for gender. The X-axis contains blood type and gender, while the Y-axis contains frequency. The frequency scale starts at 2 with a range of 2. S4 did not pay attention to the proportionality between the frequency scale and the height of the bars, so the resulting graph is not proportional.Although the range used is 2, the distance at the beginning of the scale is uneven. The graph is also incomplete because the X and Y axes are not marked with arrows, there is no graph identifier, and it does not include detailed data by day and gender.

The following shows the level of semiotic complexity of students' graphs based on several existing indicators and appropriate explanations.

Table 1. Description of the Semiotic Complexity of Student Graphs

Student Code	Cognitive Style	Visual Representation	Representation Conversion	Interpretation of Meaning	Complexity Level
S1	FD	Quite clear	Limited	Less precise	Low
S2	FD	Pretty good	Partially Successful	Inconsistent	Currently
S3	FI	Very clear	Complete and Systematic	Accurate and Consistent	Tall
S4	FI	Clear	Mostly successful	Generally correct	Tall

In general, the results of the study indicate that students with a field-independent (FI) cognitive style achieved a higher level of semiotic complexity compared to students with a field-dependent (FD) style. Subjects S3 and S4 (FI) were able to reach the highest level, namely Joint Graphs, while S1 and S2 (FD) each only reached the levels of Representing Only the Student Data and Representing Individual Results, respectively. Complete data can be seen in Table 2.

Table 2 Semiotic Complexity Level of Student Graphs

Student Code	Cognitive Style	Complexity Level	Description of abilities
S1	*Field Dependent*	*Representing Only the Student Data (level 1)*	Presents a single graph without distribution representation
S2	*Field Dependent*	*Representing Individual Results (level 2)*	Presents graphs based on distribution tables, but is limited
S3	*Field Independent*	*Joint Graphs (level 4)*	Present complex graphs with accurate scale and representation.
S4	*Field Independent*	*Joint Graphs (level 4)*	Presenting a graph of two variables with a representative comparison

The results showed that 100% of FI students were able to present graphs at the highest level, while none of the FD students achieved this level. This difference in complexity levels between groups illustrates a significant difference in the ability to represent graphs in semiotic statistics problems.

These findings indicate a strong correlation between cognitive style and graphic representation ability. Students with a field-independent style consistently demonstrate high ability in presenting graphs with complex and meaningful structures, according to semiotic indicators that include integration between data representations, scale accuracy, and symbolic interpretation. This is consistent with (Witkin, 1981) statement that FI individuals are better able to organize information analytically and are less easily influenced by external context. They can distinguish important parts of an information structure and develop relationships between these parts to form a unified, coherent understanding. In contrast, FD students are more global and rely on directly presented information, and tend to be less analytical when interpreting complex data.

In the problems aspect, FI students were able to interpret the given situation and identify important variables in the data. Meanwhile, FD students only grasped the surface of the problem without explaining the relationships between variables. In the actions aspect, FI students constructed graphs based on considerations of data distribution, consistent scales, and appropriate graph types. In contrast, FD students often constructed graphs without considering scale or data type. In the concepts aspect, FI students correctly connected graphs with the concepts of frequency, range, and distribution. Meanwhile, FD students tended to simply transfer data from tables to graphs without interpreting their meaning. Finally, in the properties aspect, only FI students were able to show representations of two variables simultaneously and explain the mathematical relationship between them. This finding reinforces Peirce's semiotic framework, which explains that the ability to understand representamen (signs/graphs) and connect them with interpretants (meanings) and objects (mathematical concepts) will reflect an individual's cognitive sophistication. The complete semiotic process was only seen in FI students.

These results support a number of similar studies. For example, research (Ningtiyas, 2021) shows that FI students are better able to use symbolic, visual, and verbal representations in an integrated manner in solving math problems. Meanwhile showed that FI students showed higher skills in visual spatial thinking. The study (Anam, 2021; Wijayaningrum, 2024) also concluded that understanding of mathematical concepts, including functions and graphs, was higher in FI students than FD. This result is also consistent with the findings (Arteaga et al., 2015) that the highest level of graph complexity (joint graphs) can only be achieved if students integrate all semiotic elements simultaneously.

Theoretically, this study confirms that cognitive style is an important variable in the process of interpreting mathematical representations, particularly in statistics learning. These findings strengthen the Peircean theoretical framework and semiotic model in mathematics education. Practically, teachers need to develop learning differentiation strategies based on students' cognitive styles. For students with learning disabilities, explicit visual guidance and gradual practice in constructing graphs, starting from single-variable representations to two-variable representations, are necessary. Meanwhile, for students with learning disabilities, teachers can facilitate exploratory projects or case studies that require complex information processing and interpretive graphing.

CONCLUSION AND SUGGESTIONS

Based on the results of the data analysis and discussion in the previous chapter, it was concluded that the differences in the semiotic complexity of students' graphs in solving statistical problems were greatly influenced by each student's cognitive style, namely field dependent and field independent. Students with a field dependent cognitive style produced graphs that could not be classified into the predetermined levels of semiotic complexity of graphs. This was because the graphs they created did not meet the criteria at each level, both in terms of completeness of the graphic elements, proportionality of the scale, accuracy of the data displayed, and the suitability between the frequency distribution table and the graphic visualization. Field dependent students tended to have difficulty separating relevant information from the existing context, resulting in unstructured graphic presentations, for example, inconsistent axis scales, the absence of arrows on the axes, not including the graphic identity, or inappropriate data placement. Their tendency to rely more on visual context or existing information without in-depth analysis resulted in graph construction that did not meet the established evaluation standards.

Meanwhile, students with a field-independent cognitive style were able to produce graphs that could be classified at levels 1 and 3 of graph semiotic complexity. At level 1, the graphs created already had basic elements such as the X and Y axes, data labels, and an appropriate graph shape, although still simple. At level 3, students not only displayed data correctly, but also paid attention to proportionality, completeness of elements, clarity of graph identity, and the suitability of the representation to the original data. Field-independent students were able to separate important information from contextual distractions, analyze data independently, and organize it into an accurate and systematic visual representation. These findings indicate that cognitive style plays a significant role in shaping the quality and level of semiotic complexity of students' graphs, where field-dependent students tended to produce graphs that did not meet the classification criteria, while field-independent students were able to achieve a higher and more structured level of complexity.

It is recommended that teachers and mathematics education practitioners pay attention to students' cognitive styles in the learning process, particularly in learning graphical representations in statistics. For field-dependent students, learning should be designed with a step-by-step approach that provides explicit visual and verbal scaffolding, such as the use of graph templates, examples of graph interpretation, and exercises in familiar contexts. Meanwhile, field-independent students can be facilitated with exploratory tasks and challenges that require data integration in complex graphs. Furthermore, it is recommended that the development of teaching materials consider the diversity of cognitive styles as part of a differentiated learning strategy. Teachers can also use the results of cognitive style identification as a basis for forming complementary collaborative learning groups. For further research, it is recommended that the scope be expanded to other mathematical contexts and with a larger number of participants to strengthen the validity of the findings.

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