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COMMOGNITIVE PERSPECTIVE ON STUDENTS' REASONING IN COMPARING MEASURES OF CENTRAL TENDENCY USING FREQUENCY POLYGONS

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Abstrak

Ukuran pemusatan data seperti rata-rata, median, dan modus merupakan konsep fundamental pada statistika yang dapat digunakan dalam pengambilan keputusan. Tujuan penelitian ini adalah untuk mendeskripsikan bagaimana mahasiswa melakukan penalaran terhadap ukuran pemusatan data ketika membandingkan dua distribusi usia pasien yang disajikan dalam bentuk poligon frekuensi dalam perspektif *commognitive*. Penelitian ini menggunakan metode kualitatif deskriptif dengan pendekatan exploratory. Mahasiswa yang terlibat dalam penelitian ini sebanyak 37 mahasiswa, empat diantaranya dipilih sebagai subjek penelitian yang terdiri atas dua subjek pada kategori kalkulatif, dan dua subjek pada kategori interpretasis visual. Instrumen penelitian ini adalah satu soal tentang ukuran pemusatan data dan pedoman wawancara. Soal tersebut memuat tiga pertanyaan yang datanya ditampilkan dalam bentuk poligon frekuensi. Data dianalisis secara tematik menggunakan kerangka kerja commognitive dari Sfard, dengan fokus pada empat komponen: *word use, visual mediators, routines, and narratives.*Hasil penelitian ini menunjukkan bahwa mahasiswa pada kategori kalkulatif lebih dominan menggunakan *visual mediator* dan *routine*. Sedangkan mahasiswa pada kategori interpretasi visual lebih menonjolkan penggunaan *word use* untuk membangun *narative*.

Kata Kunci: *commognitive*, penalaran, ukuran pemusatan data, poligon frekuensi

Abstract

Measures of central tendency, such as the mean, median, and mode, are fundamental concepts in statistics that can be used to support decision-making. The purpose of this study is to describe how university students reason about measures of central tendency when comparing two age distributions of patients presented in the form of frequency polygons, from a commognitive perspective. This study employs a descriptive qualitative method with an exploratory approach. A total of 37 students participated in the study, four of whom were selected as research subjects—two representing the calculative category and two representing the visual-interpretative category. The research instruments consisted of one problem related to measures of central tendency and an interview guide. The problem included three questions, each presenting data in the form of frequency polygons. The data were thematically analyzed using Sfard's commognitive framework, focusing on four components: word use, visual mediators, routines, and narratives. The findings reveal that students in the calculative category predominantly used visual mediators and routines. In contrast, students in the visual-interpretative category emphasized the use of word use to construct narratives.

***Keywords**: commognitive, reasoning, measures of central tendency, frequency polygon*

INTRODUCTION

Measures of central tendency, such as the mean, median, and mode, are fundamental statistical concepts that support decision-making (Rosidah & Ikram, 2021). These measures are widely applied across various domains, including education (Holt & Scariano, 2009), health (Frain, 2025; Jankowski & Flannelly, 2015), and finance (Das & Das, 2015). The ability to reason about these measures becomes increasingly important when data are presented visually, such as through graphs, which are now commonly used in statistics education

(Becerra et al., 2021; Karaca & Ay, 2025).

However, students often struggle to conceptually interpret measures of central tendency, particularly when information is displayed visually (Rosidah & Ikram, 2021). Such difficulties may stem from an inability to correctly comprehend information represented in graphs (Agus et al., 2015; Becerra et al., 2021; Cooper & Shore, 2008). Even with relatively simple visual displays such as histograms (Cooper, 2018) and ogives (Rahmatina et al., 2023), students frequently fail to accurately identify the data's center.

There are various ways to compare the mean, median, and mode, including mathematical calculations using formulas and visual inspections of distribution shapes. The use of formulas is referred to as the *calculational approach* (Landtblom, 2023; Parra-Fica et al., 2024), while the interpretation of visual data displays without explicit calculations is termed the *visual approach* (Akar & Işıksal Bostan, 2025; Landtblom, 2023). Leavy & O'Loughlin (2006) found that most preservice teachers understood the mean procedurally without relating it to the data context, whereas only a few demonstrated conceptual understanding. Similarly, Rosidah et al. (2018) found that students often used procedural strategies to solve problems on measures of central tendency but struggled to interpret the results in context, particularly for the median, suggesting limitations in their reasoning skills.

Sfard's (2008) *commognitive framework* offers a tool for analyzing students' thinking processes through the lens of communication. Within this framework, reasoning about measures of central tendency can be explored through four commognitive components: word use, visual mediators, routines, and narratives.

Prior studies have applied this framework to investigate how students construct meaning of statistical concepts through their interactions with data representations (Rahmatina et al., 2023). Karatoprak et al. (2015) found that prospective teachers often selected the mode rather than the mean, indicating a lack of reasoning about variable types. Similarly, Biehler et al. (2018) highlighted that the structure and format of data displays can significantly affect how preservice teachers interpret statistical information, particularly when the connection to contextual meaning is not explicitly recognized. These findings highlight the importance of understanding how students reason about statistical measures, especially how their procedural tendencies and interpretations of visual representations are enacted through routines and other discursive tools.

Pratiwi et al. (2022) found that incorrect use of routines can lead to cognitive conflict, especially when misaligned with the visual representations employed. This is supported by Delastri & Lolang (2023), who revealed that even correct answers can emerge from flawed procedures, indicating that conceptual understanding does not necessarily accompany correct outcomes. Therefore, it is essential to examine how routines and visual mediators interact within students' discourse, particularly when interpreting graphs such as frequency polygons.

Verbal expressions also play an important role in constructing meaning related to measures of central tendency. Within the commognitive framework, descriptive terms such as "peak" or "most frequent" serve as *word use* that help students interpret the mode. For example, students often use visual strategies such as observing the horizontal or vertical distribution to estimate the data's center, as evidenced by eye-tracking data (Boels et al., 2025).

Based on the above, this study aims to describe how students engage in reasoning about measures of central tendency when comparing two distributions of patients' ages represented through frequency polygons, using a commognitive perspective.

METHOD

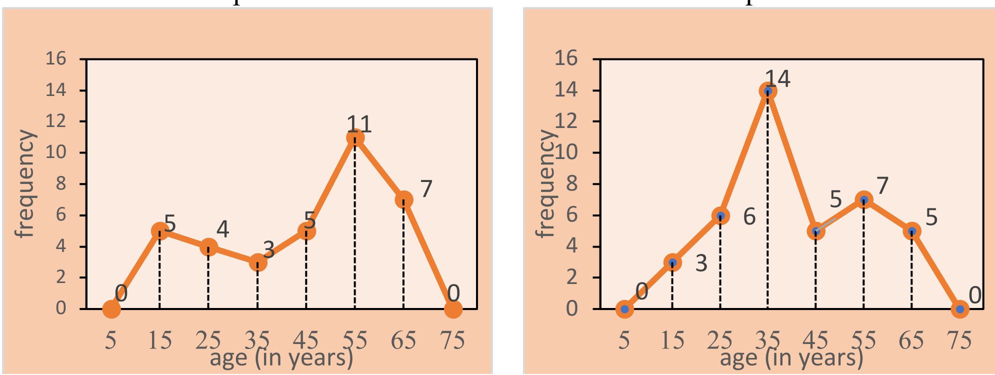
This study employed a descriptive qualitative method with an exploratory approach. The researcher aimed to describe students' reasoning when comparing the mean, median, and mode between two data sets presented in the form of frequency polygons. A total of 37 first-semester undergraduate students (6 male; 31 female) from the 2024/2025 academic year participated in this study. These students were enrolled in a Statistics Methods course in the mathematics education program at a state university in Tanjungpinang. Four out of the 37 students were selected as research subjects. This study employed criterion sampling (Patton, 2002), a technique commonly used in qualitative research to select participants who meet specific criteria relevant to the study's aims. The selection was based on the criterion that they correctly identified one of the two data groups. These four students were considered representative of those who successfully selected the correct data group.

The instruments used in this study consisted of a written task and an interview guide. The task included one problem that required students to reason about the mean, median, and mode (see Figure 1). The question asked students to choose which of the two distributions of patient ages—each from a different hospital—had a greater mean, median, and mode. The question was adapted from Rahmatina et al. (2023), which asked students to identify which of two data sets had greater variability. The main difference between the current study and that of Rahmatina et al. lies in the topic and data display: while their study focused on variability and used ogive graphs, this study focused on central tendency and used frequency polygons. A semi-structured interview format was employed to explore how students reasoned when comparing the mean, median, and mode. The interview questions were developed based on the four components of Sfard's (2008) commognitive framework: word use, visual mediators, routines, and narratives. These components served as guiding indicators for exploring the discursive tools students used when reasoning about measures of central tendency.

The data collection procedure involved seven steps. First, students completed the task involving measures of central tendency. Second, student responses were categorized into three groups: the calculational group, the intuitive interpretation group, and the non-aligned group. The *calculational group* refers to students who used formal procedures (endorsed narratives) involving formulas for mean, median, and mode across all three sub-questions. The *intuitive interpretation group* includes students who relied solely on interpreting the graphical display (frequency polygons) without using formulas. The *non-aligned group* refers to students who either did not complete all sub-questions or inconsistently used formulas—applying them in one question but not in others. Third, data were coded based on students' reasoning approaches to the measures of central tendency. Fourth, further analysis was conducted on students in the calculational and intuitive interpretation groups. Fifth, students who consistently selected the correct group (i.e., the group with the higher mean, median, or mode) were identified. Sixth, interviews were conducted with these students. Seventh, two students from each reasoning group (calculational and intuitive interpretation) were selected as the primary subjects of the study. The data analysis focused on describing which components of the commognitive framework were most dominantly used by students when comparing the mean, median, and mode.

The frequency polygon below shows the ages of patients treated at Hospital A and Hospital B

Hospital A | Hospital B



Based on the two age distributions of patients in the hospitals above:

a. Which hospital has a higher average (mean) age of patients? Why?

b. Which hospital has a higher median age of patients? Why?

c. Which hospital has a higher mode of patients' age? Why?

Figure 1. Questions on measures of central tendency in this study.

RESULTS AND DISCUSSION

There are three categories of students in solving the problems: calculative**,** visual interpretation, and those outside the calculative and visual interpretation categories. These categories are presented in Table 1.

Table 1. Classification of participants in this study

Group	Number
Calculative	19
Visual Interpretation	3
Outside the Calculative and Visual Interpretation Categories	15

In this study, the research subjects were students who consistently demonstrated reasoning when comparing the mean, median, and mode of patients' ages in two hospitals using either a calculative approach or visual interpretation. The subjects consisted of four students: two from the calculative group (S1 and S2) and two from the visual interpretation group (S3 and S4). All four subjects made correct choices in comparing the mean, median, and mode of the patients' ages. The distribution of answer choices made by students in the calculative and visual interpretation categories is presented in Table 2.

Table 2. Distribution of Students' Answer Choices

Measures of Central Tendency	Answer Choice	Number of Students	
		Calculative	Visual Interpretation
Mean	Hospital A	16	2
	Hospital B	3	1
Median	Hospital A	16	2
	Hospital B	3	1
Mode	Hospital A	16	2
	Hospital B	3	1
Total		19	3

Calculative Category

S1 and S2 compared the mean, median, and mode by performing mathematical calculations using the respective formulas for mean, median, and mode, as shown in their answer sheets (Figure 2).

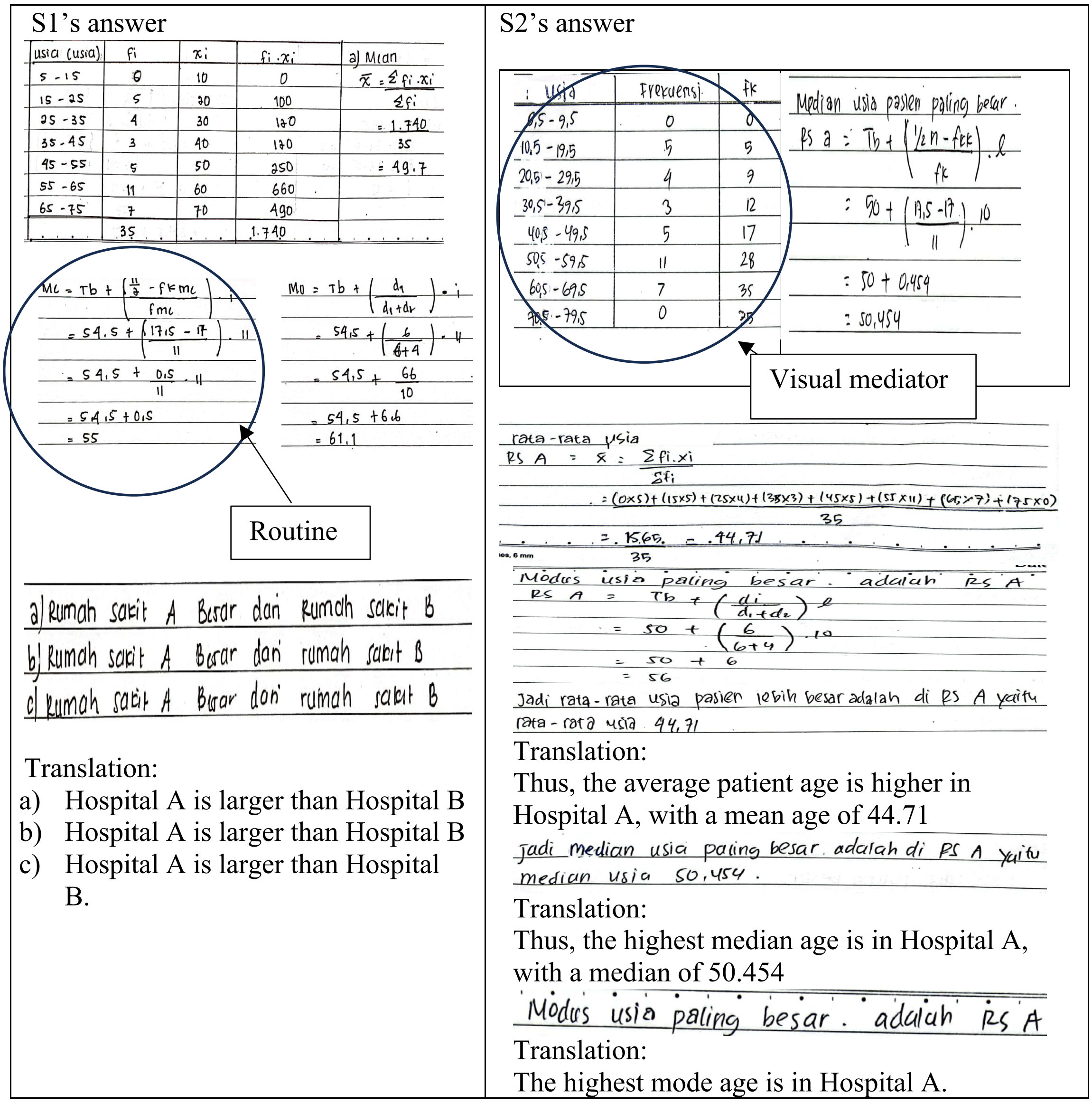


Figure 2. S1 and S2's Answer Sheets in the Comparison of Measures of Central Tendency

To gain in-depth insights into students' reasoning in comparing the mean, median, and mode, the researcher conducted interviews with subjects S1 and S2. Excerpts from the interviews between the researcher (R) and S1 and S2 are as follows:

R : Why did you use formulas to compare the mean, median, and mode of patients' ages in the two hospitals?
S1: Because the data is grouped data.
S2: Because the data is grouped, with patient age frequencies within intervals.
R: Why did you create a table?
S1: To make it easier for me to determine the mean, median, and mode.
S2: To help me calculate the mean, median, and mode more easily.
R: What does the first column (age) in the table you created represent?
S1: It shows the lower and upper class boundaries.

R: What does the x-axis represent in the frequency polygon?
S1: The class intervals or boundaries.
S2: The class midpoints of each data group, for example, 5, 15, and so on.

Based on the written responses and interview excerpts, it is evident that S1 and S2 used formulas to compare the mean, median, and mode of patient ages in Hospital A and Hospital B. They transformed the data from a frequency polygon into a table to facilitate the calculation using statistical formulas. The table served as a visual mediator. According to Boonen et al. (2014), generating accurate schematic visual representations significantly increases students' chances of correctly solving mathematical word problems compared to those who do not use such representations.

However, the visual mediator constructed by S1 did not fully align with the concept of a frequency polygon as presented in the problem. In contrast, S2's visual mediator was more consistent with the concept. Despite the inaccuracies in the visual mediators created by both S1 and S2, they were still able to arrive at correct answers when comparing the measures of central tendency. This aligns with commognitive theory (Sfard, 2008), which defines thinking as a form of communication that includes the use of visual and symbolic representations as part of mathematical discourse. In this context, the tables created by S1 and S2, although not entirely consistent with the frequency polygon in the task, served as visual mediators that enabled them to reason and make mathematical decisions.

S1's calculation steps did not yield accurate results. For example, S1 interpreted the x-axis as class boundaries and calculated class midpoints to determine the mean patient age. This misunderstanding of the x-axis in the frequency polygon led to errors in calculating the mean, median, and mode. Conversely, S2 correctly understood that the x-axis represented class midpoints and was able to accurately calculate the mean patient age. However, when determining the median and mode, S2 made mistakes in identifying class boundaries and class limits. For the modal class, S2 used class boundaries of 10.5–19.5 (to one decimal place) and calculated the lower class boundary (Lb) as 50.5 – 0.5 = 50, subtracting 0.5 from the class boundary regardless of whether it was an integer or decimal. This indicates that S2 had not yet developed a higher level of precision in dealing with class boundaries. Ideally, for more precise calculations, the class boundaries should have been represented as 50.05–59.95 and the class limits as 50.045–59.955.

From a commognitive perspective, the steps used by the subjects to determine the mean, median, and mode are referred to as routines. Pratiwi et al. (2022) found that errors in executing routines can lead to cognitive conflict when solving mathematical problems. They emphasized that "routines can either resolve or fail to resolve cognitive conflict," highlighting the importance of students understanding the procedures they use so they can apply them appropriately in problem solving.

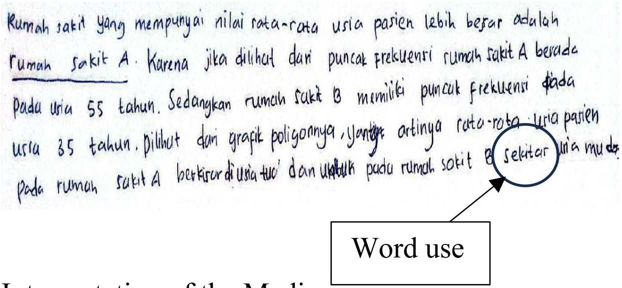
This study found that students who adopted a calculative approach tended to rely heavily on visual mediators and routines. Errors in constructing visual mediators could lead to the implementation of flawed routines. Nevertheless, these flawed routines could still result in correct answer choices. This finding is consistent with Delastri & Lolang (2023), who noted that students may arrive at correct answers even when their reasoning does not reflect a proper conceptual understanding.

Visual Interpretation Category

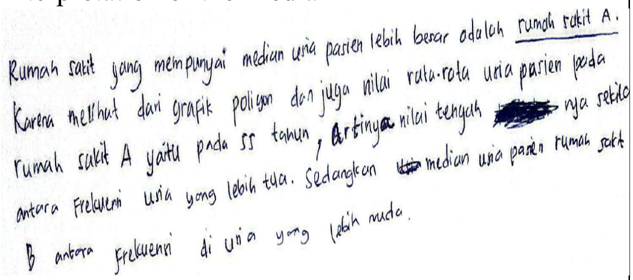
S3 and S4 compared the mean, median, and mode by observing the shape of the frequency polygon without performing any mathematical calculations using formulas for mean, median, or mode. The responses from S3 and S4 are presented in Figure 3.

S3's Response

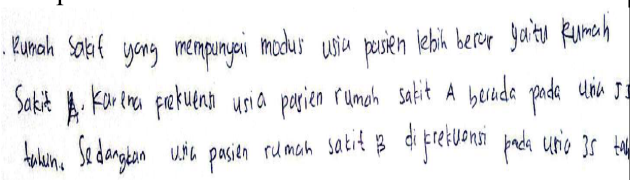
Interpretation of the Mean



Interpretation of the Median

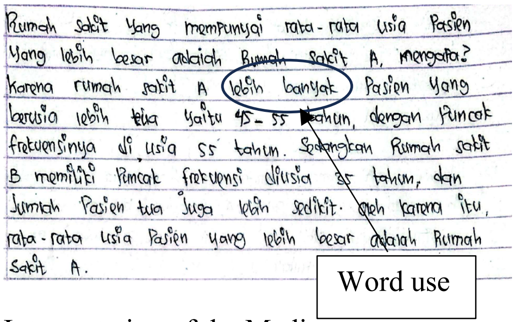


Interpretation of the Mode

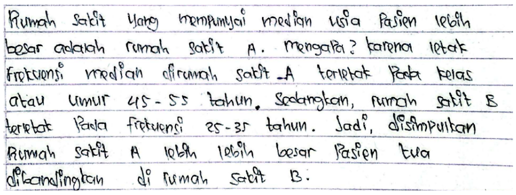


S4's Response

Interpretation of the Mean



Interpretation of the Median



Interpretation of the Mode

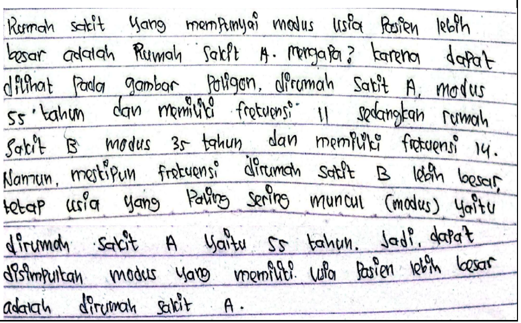


Figure 3. S3's and S4's Written Responses in Comparing Measures of Central Tendency

To gain deeper insight into students' reasoning in comparing the mean, median, and mode, the researcher conducted interviews with subjects S3 and S4. The following excerpts are taken from the interviews between the researcher (R) and the students:

R : What information did you gather from the frequency polygon in the question?

S3 : The data **distribution** and the highest frequency from each polygon..

S4 : The shape of the polygon shows a rising line toward **the peak**, connecting points that represent **frequencies** and values on the graph.

R : What is the range of older ages you referred to? (see mean response)

S3 : **Around** 45–65 years

R : What is the range of younger ages you referred to? (see mean response)

S3 : **Around** 15–35 years old.

R : Why did you state that there are fewer older patients in Hospital B? (see mean response)

S4 : Because the **frequency** in Hospital B is lower than in Hospital A, as seen from the **peak points** of the polygons.

R : What do you mean by the middle value around the frequency of older ages? (see median response)

S3 : It means that the median falls within the **older age** group.

R : Where is the median frequency

located? (see median response)

S4 : At the **frequency corresponding to the 45–55 age** group in Hospital A, so the largest value is 55 years old.

R : What does it mean that the frequency of patients in Hospital A is at 55 years old? (see mode response)

S3 : It means that **most patients** in Hospital A are 55 years old.

R : What does the x-axis in the frequency polygon represent?

S3 : Age groups or **age ranges**.

S4 : The class midpoints of each group.

R : What does the y-axis represent in the frequency polygon?

S3 : The frequency or number of patients in each polygon.

S4 : The frequency or number of data points.

R : Why didn't you use formulas to compare the mean, median, and mode of patient ages in Hospitals A and B?

S3 : because the frequency polygons for each hospital already **provided enough information** to answer the question, and **I understand how to read the graph**.

S4 : Because **I could immediately** see the differences between Polygons A and B to compare their mean, median, and mode.

Based on their written responses and interview excerpts, S3 and S4 both selected Hospital A as having higher mean, median, and mode values for patient age than Hospital B. Both relied on the frequency polygon for decision-making. S3 initially focused on data distribution and peak frequency, whereas S4 concentrated on the visual structure of the polygon—particularly the rising slope toward the peak. This difference in focus aligns with the findings of Boels et al. (2025), which indicated that students adopt a range of approaches in interpreting statistical graphs, including both distributional analysis and visual pattern recognition. Such variation reflects differences in visual processing and statistical reasoning when describing data.

S3 and S4 stated that the mean age of patients in Hospital A was higher than in Hospital B, based on the age associated with the highest peaks in each polygon. S3 claimed that Hospital A's highest frequency occurred at 55 years old, while Hospital B's was at 35. S3 indicated that the mean age in Hospital A ranged from 45 to 65, whereas in Hospital B it was around 15 to 35. S4 similarly claimed that more patients in Hospital A were in the 45–55 range compared to Hospital B. Interestingly, the students had different definitions of "older" age: S3 considered the upper limit to be 65, while S4 considered it 55.

There were also differences in their understanding of the x-axis in the frequency polygon. S3 interpreted it as age ranges, while S4 understood it as class midpoints. Neither, however, recognized that the oldest patient age in the data approached 70. Still, both correctly concluded that the average patient age was higher in Hospital A than in Hospital B.

Previous studies support these findings. Boels et al. (2025) identified five visual strategies students use when interpreting graphs, including two key strategies for comparing means: horizontal eye-movement strategies focusing on data distribution, and vertical ones focusing on the graph's shape. S3's approach reflected the former, while S4 demonstrated an initial focus on form but later incorporated similar numerical insights. These findings highlight how students integrate both visual and numerical elements when interpreting statistical graphs.

S3 used terms such as *"around," "most," "older age," "younger age,"* and *"peak,"* while S4 used *"peak," "majority," "older patients," "younger patients,"* and *"frequency"* to compare average ages. These expressions are examples of **word use**, a commognitive tool used in statistical reasoning to construct narratives and support data-driven decisions. Rahmatina et al. (2022) found that word use—whether in formal mathematical language (literate) or everyday terms with specialized statistical meaning (colloquial)—plays a crucial role as a discursive tool that helps students interpret data and justify their choices. Words such as *"around," "most,"* or *"peak"* are not merely descriptive but serve as part of discursive practices that reflect students' understanding of statistical concepts like the mean.

This can be seen, for example, in S3's claim that the median age in Hospital A falls within an older age group (45–65), while S4 interpreted the median to be around 45–55 in Hospital A and 25–35 in Hospital B. Their interpretations show differing views of what constitutes an "older" age range. S3 used the word *"around,"* while S4 used *"median frequency"* to compare medians. Cooper (2018) noted that students often misapply their understanding of variability from one graph type to another (histogram vs. bar chart) based on superficial visual similarity. They tend to interpret variability based on bar heights without understanding their different meanings across graphs. In the context of S3 and S4, their different interpretations of "older age" reflect variation in understanding data distribution structures. Word use such as *"around"* or *"median frequency"* not only function as commognitive strategies but also reveal development in representational understanding of center and spread.

To compare mode, S3 stated that the highest number of patients in Hospital A was at age 55, while in Hospital B it was at age 35. S4 identified the mode in Hospital A as 55 (frequency 11) and in Hospital B as 35 (frequency 14). Both students recognized that the comparison of modes should be based on the modal value itself (55 vs. 35), not on the frequency. This suggests that they understood how to compare modal values between two groups by focusing on the most frequent age rather than the number of occurrences. According to Garfield (2002), the essence of statistical reasoning lies in conceptual understanding of core ideas such as distribution, center, and spread.

The word use employed by S3 and S4 in comparing mode included terms such as *"most"* and *"frequency,"* which served as tools to guide their decisions in identifying the hospital with the higher modal age. This finding aligns with Landtblom & Sumpter (2025), who found that students' conceptions of central tendency are largely shaped by their mathematical knowledge and vocabulary.

S3 and S4 stated that they did not use formulas to compare mean, median, and mode because the frequency polygons already provided sufficient information, and they felt confident in reading and interpreting the graphs. In this case, they applied inductive reasoning. Inductive reasoning is often used to generate predictions or estimates, where conclusions are not certain but based on the consistency or strength of the evidence (Sauce & Matzel, 2017). In this study, the visual interpretation approach appeared to be highly appropriate for comparing mean, median, and mode. This is because such comparisons do not require precise values; estimates or ranges are sufficient as long as the central location of the data is identified. Furthermore, students who relied on visual interpretation tended to emphasize word use and narrative more prominently in their reasoning process.

CONCLUSION

Based on the findings and discussion, this study reveals that students employed two distinct approaches in comparing measures of central tendency in frequency polygons: a procedural approach based on formulaic calculations, and a visual interpretative approach that relied on observing the graphical shape. From a commognitive perspective, students in the calculative category predominantly utilized visual mediators (tables) and routines (procedural steps), even though their representations and calculations were not always accurate or conceptually sound. In contrast, students in the visual interpretation category emphasized the use of word use**,** such as *peak, older age,* and *frequency* as discursive tools to construct narratives that supported intuitive decisions when comparing the mean, median, and mode.

These two categories indicate that while students were able to select the correct answers, their reasoning processes did not fully reflect a conceptual and comprehensive understanding of statistical ideas. The main contribution of this study lies in highlighting the roles of word use**,** visual mediators**,** narratives**,** and routines as tools in students' statistical reasoning, which can be further developed through instructional practices in statistics education.

This study was limited to data represented in the form of frequency polygons. Future research could explore differences in students' reasoning from a commognitive perspective when comparing multiple data groups presented in various types of visual representations.

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