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Profiles of Conceptual, Procedural, and Technical Errors in Solving Pictogram Problems among Elementary School Students

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Abstract
The ability to comprehend pictogram material is a critical foundation for developing students' data interpretation skills from early education; however, students' mastery of this topic remains low and is rarely analyzed systematically. This study aims to analyze the profile of conceptual, procedural, and technical errors made by fourth-grade elementary students in solving pictogram problems, based on Kastolan's theory. A descriptive qualitative approach was employed, involving 11 students from a public elementary school in Purworejo Regency who had participated in statistics lessons on pictograms as outlined in the Merdeka Curriculum. Data were collected through validated pictogram tests and in-depth interviews with students who made errors. Data analysis was conducted thematically by triangulating test results and interview data to identify error patterns and root causes. The findings indicate that students' errors were dominated by technical errors (43%), followed by procedural (29%) and conceptual errors (28%). Technical errors mainly involved miscalculations and incorrect mathematical notation, conceptual errors pertained to misunderstanding icons as representations of data units, while procedural errors arose from unsystematic problem-solving steps and insufficient attention to task instructions. The main contributing factors were weak foundations in visual statistics concepts and limited practice in mathematical visual communication. This study highlights the urgency of strengthening instructional strategies that integrate conceptual, procedural, and technical aspects, as well as the need for diagnostic assessment and targeted remediation based on error type. These findings provide practical contributions for teachers and curriculum developers in building robust statistical literacy at the elementary level.

Keywords: Conceptual errors, procedural errors, technical errors, pictograms, statistics, Kastolan theory

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INTRODUCTION

Amidst the ongoing transformation of society toward a digital era characterized by a constant flow of data and information, statistical literacy has become an essential and non-negotiable requirement for the younger generation. Statistical literacy is not merely the ability to read numbers; it also encompasses the skills to understand, interpret, and make decisions based on accurate and responsible data (Engel, 2019; Schoen et al., 2025; Wild et al., 2018). The inability to master statistics from elementary school age can have a domino effect, ranging from a decline in critical thinking towards information in the media, difficulties in understanding public issues, to limited participation in data-driven socio-economic activities (Arteaga et al., 2020; Londoño & Alsina, 2023). These conditions place statistical learning in a strategic position—not only as a mathematical knowledge domain but also as a fundamental provision for students to adapt and play an active role in an increasingly dynamic digital society.

In response to these challenges, various countries, including Indonesia, have systematically integrated statistics into the elementary school curriculum, with an emphasis on mastery of concepts, skills in reading, interpreting, and presenting data in visual forms such as graphs, diagrams, and pictograms (Anuniwat & Ningtyas, 2024; Rafi & Heri, 2023). The implementation of the Merdeka Curriculum in Indonesia reflects this need, where statistical materials are introduced gradually: starting from Phase A (grades 1–2) emphasizing data grouping and presentation using tally marks and pictograms, Phase B (grades 3–4) which deepens analysis and interpretation of data in tables, pictograms, and bar diagrams, to Phase C (grades 5–6) introducing probability and more complex data analysis ((BSKAP), 2022; Bawadi et al., 2023; Fitri et al., 2024). This mapping of competencies affirms that statistical mastery at the elementary level is not only about operational technical aspects but also about interpretation and communication of data in visual contexts, such as pictograms, which are explicitly taught in grade IV.

Among various forms of visual data presentation, pictograms occupy an important position in the mathematics learning process at the elementary level. Pictograms, as data representations using easily understood images, provide concrete and intuitive access for students to comprehend, compare, and interpret data from an early age (Londoño & Alsina, 2023). The advantage of pictograms lies in their ability to bridge students' numeracy limitations, thus allowing them to practice reading and presenting data without being hindered by abstract mathematical symbols (Nur et al., 2021; Roswahyuliani et al., 2023). Proper mastery of pictograms in grade IV is crucial for building the foundation of statistical literacy, preparing students to face the flood of graphic information often encountered in daily life, both in school and in the wider community (Anuniwat & Ningtyas, 2024; Arteaga et al., 2020). Research shows that a good understanding of pictograms has a positive impact on students' ability to interpret the meaning of data in contextual and critical ways (Rong & Mononen, 2022).

Nevertheless, the importance of mastering pictograms in grade IV has not been fully matched by systematic error analysis practices regarding student learning outcomes in this topic. Without clear mapping of the patterns of errors and difficulties experienced by students in solving pictogram problems, efforts to improve statistical learning in elementary schools tend to lack clear direction and are less optimal. Error analysis conducted by teachers is crucial to specifically identify the location and type of student difficulties, be it conceptual misconceptions, incorrect use of data, or technical and interpretive errors (Pomalato et al., 2020; Rong & Mononen, 2022). By understanding students' error patterns, teachers can design more targeted interventions, whether in the form of concept strengthening, remediation, or the development of adaptive learning strategies (Dwita & Retnawati, 2022). Moreover, teachers who actively analyze student errors not only address individual learning weaknesses but also foster a culture of critical and reflective thinking in mathematics classes (Rushton, 2018). Thus, error analysis is no longer merely a diagnostic tool, but a strategic foundation for creating effective, purposeful, and transformative pictogram learning (Dwita & Retnawati, 2022; Rushton, 2018; Veloo et al., 2015).

Recent literature reviews show that previous studies discussing elementary students' errors in solving statistical problems generally have not specifically focused on error analysis in the topic of pictograms. For instance, Astari and Marsigit (2019) emphasized students' mathematical connections, while Purwati et al. (2022) focused their analysis on internal and external factors causing students' errors in statistics in general. Other studies, such as Farokhah et al. (2019), have highlighted issues of symbols and bar diagrams; Roswahyuliani et al. (2023) have focused on communication and mathematical representation, while Nur et al. (2021) and Shamsuddin et al. (2021) have concentrated on students' difficulties in learning statistics in online learning contexts. Thus, a clear research gap exists, there has not yet been a study specifically examining the profiles and sources of elementary students' errors in understanding and solving pictogram problems systematically and in depth.

One relevant theoretical approach for mapping and understanding the sources of students' errors is Kastolan's theory, which categorizes mathematical errors into three main types: conceptual, procedural, and technical errors (Hasanah et al., 2023; Kastolan, 1992; Khoiroh et al., 2023; Lubis et al., 2024). However, the application of Kastolan's theory in the context of error analysis on pictogram material at the elementary level in Indonesia is still very limited and rarely found in national literature. Existing studies mostly discuss other topics, such as arithmetic operations, geometry, or word problems, without specifically addressing pictogram issues (Bestari et al., 2024; Fitriyaningsih et al., 2024; Kartini & Alawiyah, 2023; Sonia et al., 2023). Thus, this study presents a novelty by integrating error analysis based on Kastolan's theory in pictogram material at the elementary school level, complemented by a triangulation approach using tests and interviews.

The practical implications of this research are broad, ranging from the development of remediation strategies, curriculum design improvement, to the formulation of educational policies that are more responsive to the demands of data literacy in the digital era. Specifically, this study is expected to provide a significant contribution to the development of statistical learning in elementary schools, particularly in strengthening students' statistical literacy through empirically-based interventions.

METHODS

This study employs a descriptive qualitative approach with the primary objective of analyzing the types and causes of errors made by fourth-grade elementary school students in solving pictogram problems, based on Kastolan's theory. The selection of this approach is based on the need to gain an in-depth understanding of students' thinking processes, experiences, and the social context of learning in a natural setting—something that cannot be achieved through quantitative methods (Sidiq & Choiri, 2019). Qualitative research is highly effective for exploring meaning, interpreting behaviors, and uncovering patterns or processes that cannot be measured numerically. It also enables researchers to directly explore the views, experiences, and perceptions of subjects through intensive interaction, observation, and in-depth interviews (Rukminingsih et al., 2020). Thus, this design allows for a comprehensive exploration of the dynamics of students' conceptual, procedural, and technical errors, as classified in Kastolan's theory (Hasanah et al., 2023; Kastolan, 1992; Khoiroh et al., 2023; Lubis et al., 2024). The error categories according to Kastolan's theory are presented in Table 1.

Table 1. Types of Students' Mathematical Errors According to Kastolan's Theory (Kastolan, 1992)

Error Type	Description
Conceptual	Concepts, definitions, and principles that are misunderstood or misapplied
Procedural	Steps or sequences of problem solving that are unsystematic
Technical	Calculation, notation, or symbol errors

The sampling technique used in this study is total sampling, meaning the entire population of fourth-grade students (phase B) from one elementary school in Purworejo Regency who have received instruction in statistics with the topic of pictograms according to the Merdeka Curriculum, totaling 11 students, were included as subjects in the pictogram test. Meanwhile, the interview subjects were selected purposively, namely only those students who experienced or made errors according to the categories in Kastolan's theory as indicated by their test results. This approach ensures that the data obtained are highly relevant to the focus of analysis and enables an in-depth exploration of the root causes of each type of error.

The research procedure consists of five main stages, as generally illustrated in Figure 1.

Figure 1. Research Stages (adapted from Rahmawati et al., 2024)

The *first* stage is the administration of the Pictogram Test, using three questions from the Final Semester Summative Assessment Package for the 2024/2025 academic year, which has been validated by the government. The questions were developed based on three main indicators: (1) students' understanding of pictograms as a means of data presentation (Test-1), (2) the ability to read and interpret data in the form of pictograms (Test-2), and (3) the skill to present simple data in pictogram form using representative images (Test-3). An example of the test instrument, specifically Test-3, is presented in Figure 2 to provide a concrete illustration of the problem used in the study.

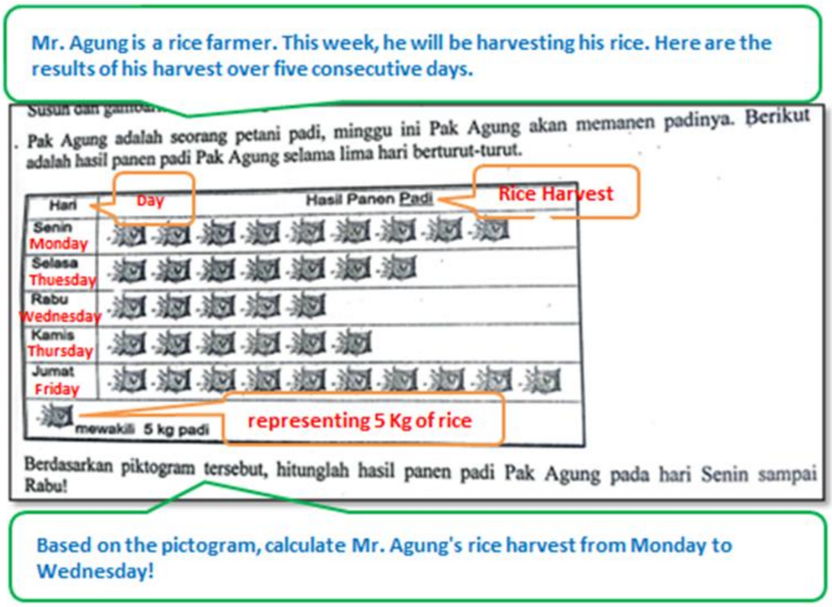

Figure 2. Pictogram Test (Test-3)

The *second* stage is the correction of test answers and the categorization of students' error types. Each student's answer sheet was systematically reviewed and classified into conceptual, procedural, or technical error categories according to the indicators in Kastolan's theory as outlined in Table 1. The *third* stage is conducting in-depth interviews, carried out only with students identified as having made errors on the test. The interviews were conducted in a semi-structured manner, recorded, and transcribed to ensure data accuracy and to reveal the root causes of the students' errors. The *fourth* stage is data analysis, which was performed qualitatively using thematic analysis techniques. This process includes identifying dominant error patterns, analyzing the content of interview transcripts, and triangulating test results with interview data to strengthen the validity of interpretations. The analysis results are presented narratively and reinforced with tables of error type distribution and direct quotes from students. The *fifth* stage is the formulation of improvement recommendations based on the types of errors found. These recommendations are intended to provide strategic input for teachers in designing instructional interventions, remediation, or the development of adaptive learning strategies tailored to student needs.

Data validity is ensured through source triangulation (test results and interviews), while reliability is maintained through systematic analysis procedures and transparent documentation. The entire research process is conducted with attention to ethical principles, such as obtaining informed consent from participants and protecting the confidentiality of student identities. With these structured and integrated research stages as described, this study is expected to make a significant contribution to mapping and improving statistics learning at the elementary school level, especially regarding pictogram topics.

RESULTS & DISCUSSION

RESULT

Profile of subjects and test administration

This study involved 11 fourth-grade students from a public elementary school in Purworejo Regency. Student identities were anonymized using the following initials: ANKN, ANA, FH, FK, FSS, MAW, MCAA, MZA, MWA, NN, and RAN. All subjects participated in a pictogram test consisting of three items, aimed at measuring their understanding of pictograms as a medium for data presentation, their ability to read and interpret pictogram data, and their skill in representing data in the form of pictograms. After the test, interviews were conducted with students who made errors.

Distribution of Pictogram Test Answers

A recap of correct (T) and incorrect (F) answers for each student on the three pictogram test items is presented in Table 2.

Table 2. Distribution of Correct (T) and Incorrect (F) Answers on the Pictogram Test

No	Initial Participant	Test-1	Test-2	Test-3
1	ANKN	T	F	F
2	ANA	T	T	F
3	FH	F	T	F
4	FK	T	T	T
5	FSS	F	T	F
6	MAW	F	T	F
7	MCAA	T	T	T
8	MZA	F	F	F
9	MWA	T	T	T
10	NN	T	T	T
11	RAN	T	T	F

Table 2 shows the number of students who answered incorrectly, namely in Test-1: 4 students (36.36%); Test-2: 2 students (18.18%); and Test-3: 7 students (63.64%). Meanwhile, four students (FK, MCAA, MWA, and NN) answered all questions correctly. When reviewed based on the learning indicators for pictograms: in Test-1, there were 4 students who answered incorrectly, indicating that the indicator of understanding pictograms as a means of presenting data was not achieved by these students. This shows that there are still students who do not understand the function of symbols or icons in pictograms as representations of data. In Test-2, there were 2 students who answered incorrectly, indicating that the indicator of the ability to read and interpret data in the form of pictograms was not achieved by these students. These students had difficulty interpreting the information or meaning of the data presented in the images. In Test-3, there were 7 students who answered incorrectly, indicating that the indicator of the ability to present data in the form of pictograms was not achieved by the majority of students. These errors include the failure to use images as representations of quantity and/or to perform correct calculations in the visual presentation of data.

Based on the test results, the highest number of errors occurred in Test-3, with 7 students (63.64%) answering incorrectly. Therefore, the focus of data presentation and subsequent analysis will be on the 7 students who made errors in Test-3, namely: ANKN, ANA, FH, FSS, MAW, MZA, and RAN.

Distribution of Error Types and Their Causes

Error identification refers to Kastolan's theory: conceptual errors occur when students misunderstand the meaning of icons/images in pictograms; procedural errors occur when students make mistakes in the steps or sequence of reading or presenting data; and technical errors occur when students make calculation (addition/multiplication) or notation mistakes. The results of error identification are presented in Table 3.

Table 3. Distribution of Error Types Among 7 Students with Incorrect Answers in Test-3

No	Initials	Conceptual	Procedural	Technical
1	ANKN	-	√	√
2	ANA	-	-	√
3	FH	√	√	√
4	FSS	√	√	√
5	MAW	√	√	√
6	MZA	√	-	-
7	RAN	-	-	√

Table 3 shows the number of students for each type of error (in Test-3): conceptual errors: 4 students; procedural errors: 4 students; and technical errors: 6 students. Thus, the total number of errors made by students is (4 + 4 + 6) = 14 errors. The percentage of each type of student error can be seen in Figure 3.

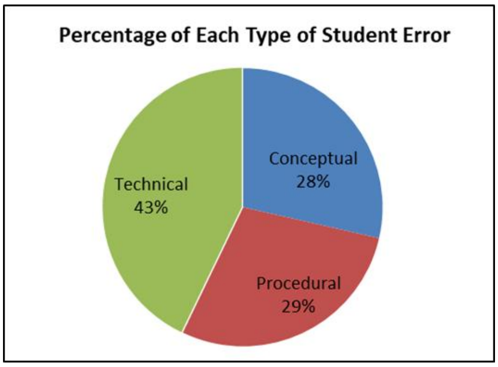

Figure 3. Percentage of Each Type of Student Error

As shown in Figure 3, 28% of errors were conceptual, 29% were procedural, and 43% were technical.

Analysis of Conceptual Errors

Four students (FH, FSS, MAW, MZA) made conceptual errors, particularly in not understanding that one sack icon represents 5 kg. Figure 4 presents the written answer of Subject-MZA.

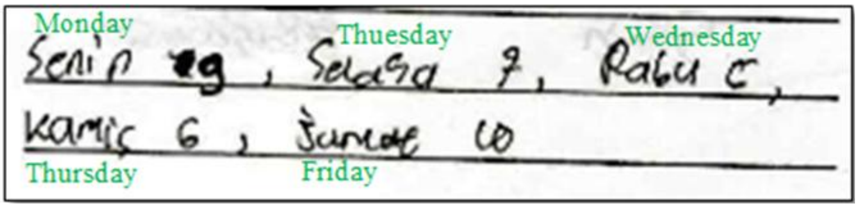

Figure 4. Written Answer of Subject-MZA

Figure 4 shows that Subject-MZA was only able to count the icons without converting them to kilograms. The answers from FH, FSS, and MAW also do not demonstrate adequate conceptual understanding.

Relevant interview excerpts between the researcher (P) and subjects:

P : *"What do you think the rice sack icon means?"*
MZA : *"I thought one sack picture means one kilogram."*
P : *"Do you know how many kilograms one picture represents?"*
FH : *"I don't know, Mrs."*
FSS : *"I don't know yet, Mrs."*
MAW : *"I don't understand the meaning of the picture in the question."*
MZA : *"I didn't know what 'represents' meant, so I ignored it."*
FSS : *"I didn't read the note at the bottom, I just looked at the picture."*
MAW : *"I've never been told that a picture can mean more than one."*

Analysis of Procedural Errors

Four students (ANKN, FH, FSS, MAW) made procedural errors, for example by not following the correct calculation sequence as instructed in the question. Figure 5 presents the written answer of Subject-ANKN.

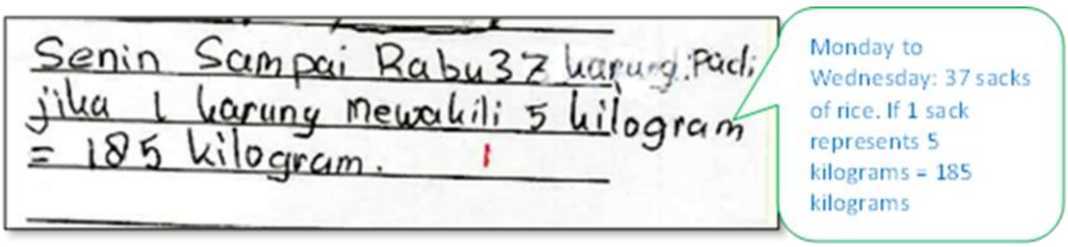

Figure 5. Written Answer of Subject-ANKN

Figure 5 shows that Subject-ANKN summed the harvest for all days, instead of only summing the harvest from Monday to Wednesday.

Relevant interview excerpts between the researcher (P) and the subjects:

P : *"How did you calculate Pak Agung's harvest?"*
ANKN : *"I counted all the sacks, then multiplied by 5."*
FSS : *"I just added everything, then multiplied."*

MAW : *"I was confused, whether to add first or multiply first, so I just wrote all the totals."*
P : *"What do you think caused your mistake in answering Test-3?"*
ANKN : *"I didn't read the question carefully, I thought all the days should be summed."*
FSS : *"I'm used to adding everything up, not thinking about the order of days."*
FH : *"I worked on another piece of paper, so I forgot the sequence when writing the answer sheet."*

Analysis of Technical Errors

There were 6 students who made technical errors in Test-3, primarily calculation or notation mistakes. Figure 6 shows the written answer of Subject-RAN.

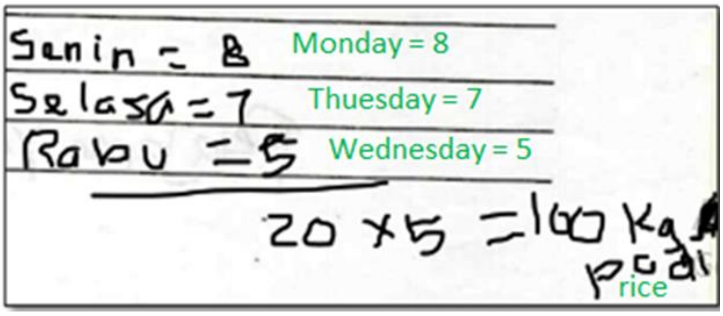

Figure 6. Written Answer of Subject-RAN

Figure 6 shows that Subject-RAN made a mistake in counting the icons on Monday, writing 8 instead of the correct 9. Figure 7 presents the written answer of Subject-ANA.

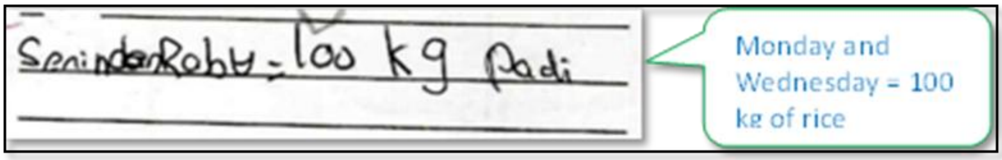

Figure 7. Written Answer of Subject-ANA

Figure 7 shows that Subject-ANA made an error in calculating the total rice harvest from Monday to Wednesday due to mistakes in counting the icons for each day.

Relevant interview excerpts between the researcher (P) and the subjects:

P : *"How did you add up Pak Agung's harvest?"*
ANA : *"I wrote 45 + 35 + 25, but I calculated it as 100, when it should have been 105."*
RAN : *"Earlier, I wrote 8 sacks, but it should have been 9. I wasn't careful when counting the pictures."*
MAW : *"I'm still confused, sometimes I multiply, sometimes I add, not sure which one comes first."*
P : *"Your final answer is not correct. Didn't you check your work?"*
ANA : *"I was in a hurry, Ma'am, so I didn't have time to check again."*
RAN : *"No, Ma'am, I just wrote it straight away."*
FSS : *"I was afraid I would run out of time, so I didn't check the calculation."*

Recapitulation of Causes of Student Errors (in Test-3)

Table 5 presents a summary of the causes of student errors based on the interview analysis.

Table 5. Recapitulation of Causes of Student Errors

Error Type	Main Causes (from Interviews)
Conceptual	Did not understand the meaning of the icon/image as a unit; did not read the note
Procedural	Incorrect sequence of steps, habit of summing all data; did not write the steps
Technical	Careless calculation, rushed, did not re-check, confused about calculation steps

DISCUSSION

This study reveals that errors made by fourth-grade elementary students in solving pictogram problems are dominated by technical errors, followed by conceptual and procedural errors. Most students are not yet able to understand the meaning of pictogram icons as representations of data units, are insufficiently systematic in their problem-solving procedures, and frequently make mistakes in arithmetic operations. Only a small proportion of students are able to complete all stages correctly.

These findings indicate that statistical literacy and visual representation skills among elementary students remain low, particularly in aspects of reading, interpreting, and presenting data in pictogram form. The results of this study are highly relevant to previous research that highlighted the weakness of basic statistical skills, mathematical representation, and visual communication abilities among Indonesian elementary students (Farokhah et al., 2019; Nur et al., 2021; Roswahyuliani et al., 2023).

The results of this study also reinforce earlier findings regarding the types and main sources of student errors in visual statistics material. Conceptual errors are caused by students' misunderstandings of icons/images in pictograms as data units, for example, thinking that one icon equals one unit instead of five units (Farokhah et al., 2019; Nur et al., 2021). This is in line with interview results where students admitted to not paying attention to the legend or not understanding the meaning of the icon. Procedural errors occur when students follow incorrect sequences of problem-solving steps, such as immediately summing the data without converting the icons to the correct units (Nur et al., 2021; Shamsuddin et al., 2021). Additionally, students often do not read instructions carefully, rush through the problems, and fail to write down their steps systematically. Technical errors arise from calculation mistakes (addition/multiplication), incorrect notation, or lack of accuracy (Farokhah et al., 2019; Roswahyuliani et al., 2023). Furthermore, students frequently make simple, repetitive errors due to weak mastery of basic arithmetic operations. Recent literature also highlights that these errors are rooted in a weak foundation of visual statistical concepts, minimal practice in mathematical visual communication, and suboptimal contextual teaching approaches (Habibie et al., 2023).

The final stage of this research is to provide recommendations for improvement. Based on the findings and the literature review, the following are several structured recommendations to enhance statistics learning, especially pictograms, in elementary schools.

Recommendations for Improving Statistics (Pictogram) Learning Strategies

First, integrate conceptual and procedural knowledge in statistics learning, particularly in the context of pictograms. Teachers should balance the reinforcement of conceptual understanding (such as the meaning of icons, unit relationships, and data representation) with operational procedures (steps to create, read, and interpret pictograms), as both aspects strengthen each other and must be developed synergistically (Legesse et al., 2020; Nahdi & Jatisunda, 2020). *Second*, implement mathematics discourse-based instruction, in which students are encouraged to explain, reason, compare solutions, and argue; this strategy has proven effective in enhancing students' conceptual and procedural understanding (Smith, 2018; Walls, 2021). *Third*, regularly strengthen both visual and verbal communication skills so that students are accustomed to converting visual data into mathematical narratives and vice versa, as well as being able to explain pictograms both orally and in writing. This is important for building visual data literacy and strengthening conceptual understanding (Nahdi & Jatisunda, 2020; Roswahyuliani et al., 2023). *Fourth*, use inquiry-based and problem-based learning models to encourage students to collect real data, create pictograms, analyze, and discuss the results within real-life contexts or current issues, making learning more relevant and meaningful (Franklin & Bargagliotti, 2020; Habibie et al., 2023; Schoen et al., 2025). *Fifth*, vary learning media by utilizing concrete manipulatives, simple digital applications, and infographics to train students' skills in data representation and interpretation (Farokhah et al., 2019; Roswahyuliani et al., 2023).

Recommendations for Improving the Evaluation Process

First, conduct regular error-based diagnostic assessments to diagnose and identify students' conceptual, procedural, and technical errors. The follow-up to this assessment should be focused and accurate remediation, such as addressing icon misconceptions, practicing systematic steps, or strengthening basic calculation skills (Delastri & Lolang, 2023). *Second*, develop formative assessments that evaluate not only the final results but also students' thought processes, argumentation, and discussions. This is important to capture and address error patterns early (VanLehn et al., 2021; Webb et al., 2019). *Third*, carry out specific remediation tailored to the students' error profiles (conceptual/procedural/technical), either through individual exercises, class discussions, or contextual assignments (Delastri & Lolang, 2023; Nahdi & Jatisunda, 2020).

Recommendations for Enhancing Teacher Competence

First, teachers need to develop their professional competence through specialized training, lesson study, and active participation in learning communities and collective reflection. Training based on inquiry, mathematical discourse, and error-handling strategies is crucial for improving the quality of statistics visual learning (Franklin & Bargagliotti, 2020; Schoen et al., 2025). *Second*, teachers are encouraged to foster a classroom culture that manages errors constructively, such as through scaffolding and peer correction, as well as developing student collaboration in small groups. These interactions increase students' confidence, understanding, and independence in correcting errors (Benecke & Kaiser, 2023; Legesse et al., 2020).

This research contributes to scientific development by providing a detailed mapping of students' error profiles based on Kastolan's theory on the topic of pictograms, a study that is still rarely conducted at the elementary school level in Indonesia. The results can serve as an important reference for teachers and curriculum developers in improving statistics learning, particularly on the topic of pictograms. However, this study also has several limitations. First, the sample size was limited and taken from only one elementary school, so the results cannot be generalized nationally. Second, the focus of the study was only on the topic of pictograms and grade IV, so error patterns at other grade levels and topics were not covered. Third, although data triangulation was carried out through tests and interviews, the instruments used were still limited to certain question formats. In the future, further research can be conducted by expanding the sample, conducting studies across grade levels or other visual statistics topics, and testing the effectiveness of improvement interventions based on the error profiles that have been identified.

CONCLUSION

This study reveals that the errors made by fourth-grade elementary school students in solving pictogram problems are predominantly technical errors, followed by conceptual and procedural errors. Technical errors mainly arise in calculation operations and notation writing, while conceptual errors stem from students' lack of understanding of icons as representations of data units. Meanwhile, procedural errors occur due to unsystematic sequences of problem-solving steps and insufficient attention to instructions. The primary root of these errors lies in weak conceptual understanding of pictograms, minimal practice in mathematical visual communication, and ineffective teaching methods. Only a small proportion of students were able to answer all pictogram questions correctly across the assessed indicators.

Based on these findings, several strategic steps are recommended: (1) strengthening conceptual and procedural understanding through discussion-based, inquiry-based, and problem-based learning; (2) conducting regular diagnostic assessments and providing targeted remediation based on the specific types of errors identified; (3) enhancing teacher competence through professional development and collaborative reflection; and (4) utilizing a variety of visual media and simple digital applications to support students' learning experiences. Through these measures, it is expected that students' foundational statistical literacy—especially in interpreting pictograms—can be strengthened from an early age, better preparing them to meet the challenges of data literacy in the digital era. The findings of this study provide a crucial reference for developing adaptive, contextual, and meaningful statistics instruction at the elementary school level.

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