Context-Based Line Graph Comprehension: Do Teacher Education and Experience Make a Difference?

Sitti Maesuri Patahuddin
University of Canberra
Sitti.Patahuddin@canberra.edu.au

Andi Mulawakkan
Universitas Muhammadiyah Makassar
andi.mulawakkan@unismuh.ac.id

Ajay Ramful
Mauritius Institute of Education
a.ramful@mie.ac.mu

This cross-sectional study examines participants' comprehension of line graphs at different career stages, comparing first-year and third-year pre-service teachers (PSTs) with in-service teachers (ISTs). A 23-item line graph task aligned with Curcio's framework—*Reading the data, Reading between the data, and Reading beyond the data*—reveals persistent challenges in *Reading beyond the data*. ISTs outperformed PSTs, suggesting practical experience enhances interpretation. However, no significant differences emerged between first- and third-year PSTs, challenging assumptions that teacher education fosters progressive development in graph interpretation skills.

Introduction

The ability to accurately read, interpret, and infer from graphical representations is a fundamental aspect of critical thinking and problem-solving in a data-rich world (Glazer, 2011; Romero Ariza et al., 2024). Graphs, charts, and plots, omnipresent across disciplines from science to social studies, are pivotal for visualising complex information, making informed decisions, and discerning trends. These skills are crucial for students to effectively navigate and interpret the information-rich world around them (Rodriguez & Jones, 2024). The importance of these skills extends beyond student learning to the educators responsible for their development.

Teachers, as primary facilitators of learning, must possess the competence to interpret and teach graph-related content. This ability is a key component of their pedagogical content knowledge, influencing their effectiveness in guiding students through the intricacies of graph comprehension (Freedman & Shah, 2002; Friel et al., 2001). Teachers not only need to understand graphs themselves but also require the skills to effectively teach this content, helping students to construct key concepts, interpret graphs in relation to contextual situations as well as overcome difficulties and misconceptions (Glazer, 2011; Kerslake, 1981). As a matter of fact, studies indicate that both in-service and pre-service teachers often struggle with interpreting and teaching of graph-related content (Glazer, 2011; Patahuddin & Lowrie, 2019). Research in this area, therefore, is invaluable to understand the particularities that make graph comprehension accessible or constraining to both preservice and in-service teachers. This study also contributes to provide a developmental perspective of graph comprehension from pre-service to in-service education and enhances our current understanding of graph comprehension.

The current investigation advances our understanding of context-based line graph interpretation skills in a sample of 256 pre- and in-service teachers. It aims at exploring the knowledge growth of teachers by analysing the developmental trajectory of graph interpretation skills across 3 cohorts—Year 1 and Year 3 pre-service teachers, and in-service teachers. The following research question guided the study: *How do graph interpretation skills differ across first-year and third-year pre-service teachers and in-service teachers, and what does this reveal about their developmental progression?*

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The Research Gap: Understanding the Developmental Progression of Line Graph Interpretation from Pre-Service to In-Service

While extensive research has been conducted on enhancing in-service teachers' graph interpretation skills through various interventions, there remains a notable gap in understanding how these abilities are developed during pre-service teacher education. This stage is critical as the competencies formed during pre-service training profoundly influence future educational practices. Incorporating pre-service teachers into graph interpretation research is essential to evaluate their initial skills and misconceptions, providing a basis for targeted educational strategies that could profoundly impact their future teaching effectiveness.

The literature consistently highlights the importance of graph interpretation skills, suggesting that these competencies are crucial for teachers from the onset of their careers due to the increasing complexity of graphical data in educational settings (Glazer, 2011; Leinhardt et al., 1990; Zeuch et al., 2017). However, studies specifically focusing on the development of these skills during pre-service teacher training are sparse. The work of Ates & Stevens (2003) indicates that different teaching modalities can influence skill development, pointing to the need for a diverse range of instructional approaches. Thus, investigating how pre-service teachers acquire and refine these skills can close a significant research gap and provide essential data for enhancing teacher education curricula to better meet the demands of contemporary education in data literacy.

Additionally, previous research has identified persistent challenges in graph interpretation among pre-service and in-service teachers (e.g., Alacaci et al., 2011; Zeuch et al., 2017), suggesting that misconceptions do not necessarily diminish with experience. Studies reveal that in-service teachers, like their students, often misinterpret line graphs by treating them as literal representations of physical events rather than abstract representations of data (Glazer, 2011; Leinhardt et al., 1990). This 'iconic graph difficulty' leads to fundamental errors in understanding the variables and relationships depicted, indicating a deep-rooted misconception that could be addressed beginning in pre-service training.

Moreover, the persistence of these interpretation challenges among experienced teachers (Patahuddin & Lowrie, 2019) underscores a lack of effective professional development in this area. It suggests a broader systemic issue in ongoing education that allows these misconceptions to perpetuate, affecting both teaching and learning outcomes. Research focusing on the inception and correction of these misconceptions during pre-service education could therefore play a pivotal role in breaking this cycle of misunderstanding and enhancing overall educational quality.

The study by Patahuddin & Lowrie (2019) focusing on in-service teachers' graph interpretation skills found three key insights: firstly, teachers struggled with tasks that required 'reading beyond the data,' indicating difficulties in interpreting graphs beyond their explicit content. Secondly, these challenges were more pronounced in teachers teaching only one grade level. Thirdly, the study discovered that these difficulties occurred irrespective of the teacher's gender. The study adds to the growing body of evidence that misconceptions in line graph interpretation are not limited to students but extend to teachers as well, affecting their ability to impart these crucial skills to their students.

Overall, there is a need for research that probes the development of graph interpretation skills at the pre-service level to in-service teachers. Such studies would not only fill a critical gap in the academic literature but also potentially lead to significant improvements in educational practice by equipping future teachers with the necessary skills to handle the complex data-centric challenges of the real world.

Theoretical Framework for Interpreting Graphs

Various theories and taxonomies have been proposed to understand the processes involved in graph interpretation. Shah and Hoeffner (2002) suggested that successful graph interpretation involves three steps: (1) identifying and encoding graph features, (2) interpreting general relationships, and (3) relating these relationships to the disciplinary context. Bertin's (1983) semiotic theory divides graph reading into three stages: external identification (recognising graph features like labels and units), internal identification (understanding components and visual arrangements), and perception of pertinent correspondences (comprehending data through the interaction of external and internal features). Curcio's three-tiered framework (1987) considers factors such as prior knowledge, mathematical content, and graph form, correlating to three levels of interpretation ability: (1) reading the data (extracting information directly from the graph), (2) reading between the data (identifying relationships within the graph data), and (3) reading beyond the data (making inferences and predictions from the graph data).

Arteaga et al. (2015) used Curcio's theory to assess prospective primary school teachers' abilities to read and construct graphs. They found that while more teachers could construct complex graphs, fewer could interpret data at the highest level, 'reading beyond the data'. Similarly, Jacobbe and Horton (2010) found that competent graph interpreters among U.S. primary school teachers struggled with 'reading beyond the data'. These studies highlight the need for improvements in teacher training and professional development programs. The commensurability of the current research with the aforementioned studies as related to teachers, motivated the selection of Curcio's framework.

Methods

Research Context and Participants

This cross-sectional study examines line graph interpretation skills among 256 participants in Eastern Indonesia, divided into three cohorts: **Cohort 1** (85 first-year pre-service secondary teachers), **Cohort 2** (105 third-year pre-service secondary teachers), and **Cohort 3** (66 in-service secondary teachers) with an average of 9.4 years of teaching experience (Years 7–9). These cohorts represent different stages of teacher education, with pre-service teachers at varying levels of training and in-service teachers having completed at least a four-year undergraduate degree in education. The first-year preservice teachers had studied two semesters of mathematics content courses such as Calculus I and II, Trigonometry, Statistics, Elementary Algebra, Geometry and Number Theory along with other education-related modules. On the other hand, the third-year preservice teachers had studied Discrete mathematics, Real Analysis, Mathematical Modelling among others. It should also be highlighted that the university established their curriculum based on National Standard of Higher Education (NSHE) and the Indonesian Qualification Framework (Abadi & Chairani, 2020). All participants provided informed consent voluntarily. They were made aware of the study's aims, procedures, and potential implications prior to their participation, and their anonymity has been preserved throughout.

To evaluate graph interpretation skills, a 23-item True-False test (Refer to Table 1) was used, sourced from a graph test, empirically designed and validated to assess teachers' conceptualisation of graph comprehension in relation to line graphs depicting variable speeds of two cars (Patahuddin & Lowrie, 2019). The complexity of this task emanates from the fact that the speed of two cars have to be compared through two intersecting line graphs. Each test item was classified into one of Curcio's levels of graph interpretation—*Reading the data, Reading between the data, and Reading beyond the data*—by a team of eight researchers, yielding a Fleiss Kappa inter-rater reliability of 0.7, suggesting substantial agreement.

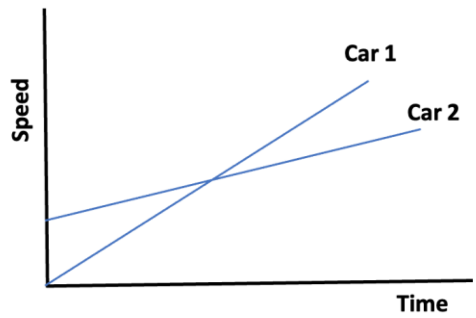
The tests, conducted in Bahasa Indonesia, took approximately 30 minutes and were administered in a paper-and-pencil format to maintain consistency across sessions. Figure 1 shows the task context. The students were presented with a set of 23 statements and they had to rate whether it is true or false.

Figure 1

Task Associated with Context-Based Line Graph Interpretation Skills (Patahuddin & Lowrie, 2019, p. 790)

Task:

Carefully observe the movement of two cars represented in the graphic.



The graphic shows the relationship between speed and time.
The horizontal axis represents the travel time of the cars.
The vertical axis represents the speed of the cars.
You are asked to decide TRUE or FALSE of each following statement.
TRUE means always correct in any condition.
FALSE means it could be incorrect in a certain condition.

Results

The items in the questionnaire have been categorised according to the three dimensions of Curcio's framework. The last category 'Reading beyond the data' was further subdivided into Type I and Type 2. Type 1 requires an understanding of the graph's content that impacts its interpretation (such as interpreting the slope as indicative of changes in speed; understanding distance in terms of speed and time) while Type 2 entails pre-existing ideas regarding the contextual setting or personal experiences related to the content of the graph, which influence interpretation (for instance, perceiving a connection that is not directly perceptible but has to be inferred).

Table 1 shows the proportion of correct responses from three groups of respondents. Notably, the data illustrates a progressive improvement in the correctness of responses from Year 1 pre-service teachers to in-service teachers. It highlights the enhancement of interpretation skills through experience and education. Moreover, Figure 2 shows that certain questions, notably Q1, Q2, Q7, Q13, Q16, Q18, and Q22, were challenging for all cohorts, with less than 50% accuracy. These items either require relatively higher order interpretation or are intuitively disorienting. Additionally, the varying difficulty level across different categories is evident, with particularly lower success rates in the "Reading beyond the data Type 2" questions (e.g., Q1, Q2, Q14, Q19), suggesting these require higher interpretation skills. Specific questions, such as those concerning the initial car speed and speed changes between the cars (i.e., Q4 & Q5), show markedly higher correctness rates, indicating some concepts might be more intuitively grasped by the respondents.

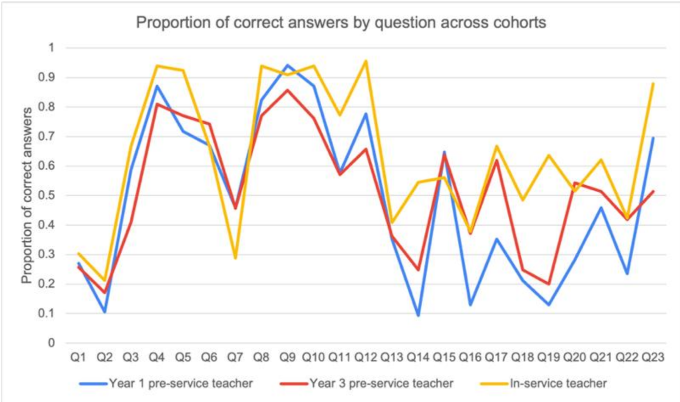
Table 1

Progression of Line Graph Interpretation Skills Among Pre-Service and In-Service Teachers

Item	True-false statement	Key answer	Proportion of correct answer		
			Year 1 PST	Year 3 PST	IST
Reading the data					
Q4	Car 1 and Car 2 have different initial speeds	T	0.87	0.81	0.94
Q5	Car 1 had an initial speed of 0 whilst Car 2's initial speed was greater than 0	T	0.72	0.77	0.92
Reading between the data					
Q6	The speed of Car 1 is always greater than the speed of Car 2 at any time	F	0.67	0.74	0.67
Q8	Car 1's speed will be greater than Car 2's speed after a certain time	T	0.82	0.77	0.94
Q10	Car 1's speed continuously increases	T	0.87	0.76	0.94
Q11	Car 2's speed is constant	F	0.58	0.57	0.77
Reading beyond the data Type 1					
Q3	Car 1 and Car 2 will meet if they travel at the same speed for the same duration.	F	0.59	0.41	0.67
Q9	The change in speed for Car 1 and Car 2 differs	T	0.94	0.86	0.91
Q12	The change in speed of Car 1 is greater than Car 2	T	0.78	0.66	0.96
Q13	The change in speed of both cars are constant	T	0.35	0.36	0.41
Q16	The distances covered by Car 1 and Car 2 are different	F	0.13	0.37	0.38
Q17	At all time, Car 1 covered a greater distance than Car 2	F	0.35	0.62	0.67
Q20	The initial position of Car 1 and Car 2 cannot be identified from the graph	T	0.28	0.54	0.52
Q21	The route travelled by Car 1 and Car 2 cannot be identified from the graph	T	0.46	0.51	0.62
Q22	The graph does not show whether or not Car 1 and Car 2 meet at a certain point	T	0.24	0.42	0.42
Q23	The final destination of Car 1 and Car 2 cannot be identified from the graph	T	0.69	0.51	0.88
Reading beyond the data Type 2					
Q1	Car 1 and Car 2 meet in one place	F	0.27	0.26	0.30
Q2	Car 1 and Car 2 meet at the intersection	F	0.11	0.17	0.21
Q7	Car 1 will catch up to Car 2 then overtake it	F	0.46	0.46	0.29
Q14	The initial location of Car 1 and Car 2 always differ	F	0.09	0.25	0.55
Q15	Car 1 left a few minutes after Car 2	F	0.65	0.64	0.56
Q18	Car 1 and Car 2 drove to the right	F	0.21	0.25	0.49
Q19	Car 1 had a steeper route than Car 2	F	0.13	0.20	0.64

Figure 2

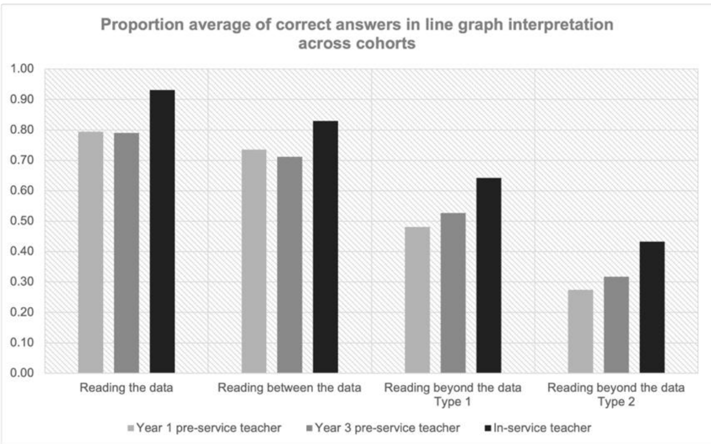
Line Graph Comparing the Proportion of Correct Answers for Each Item Among Three Cohorts



Moreover, the bar graph (Figure 3) compares the average proportion of correct answers in the line graph interpretation across the three cohorts and along the three-tiered framework of Curcio. In-service teachers consistently showed higher proportions of correct answers across all categories, indicating superior graph interpretation skills. Year 3 pre-service teachers performed better than Year 1 pre-service teachers, particularly in the more complex categories, suggesting a developmental progression in their graph interpretation abilities.

Figure 3

Comparative Analysis of Graph Interpretation Skills Among Pre-Service and In-Service Teachers



A Kruskal-Wallis test indicated a significant difference in performance across the three categories of teachers $\chi2$ (2) = 50.0, N = 256, $p < 0.01$. The median scores were 11, 12 and 14 for Cohorts 1, 2 and 3 respectively. Post-hoc comparisons indicated significant differences between Cohorts 1 and 3 ($p < 0.01$) and Cohorts 2 and 3 ($p < 0.01$). However, there were no significant differences between Cohort 1 and Cohort 2 ($p = 0.05$). These findings suggest that in-service teachers significantly outperformed pre-service teachers, with the largest gap between Year 1 pre-service and in-service teachers. Importantly, no significant differences were obtained between Year 1 and Year 3 pre-service teachers.

Discussion and Conclusion

This study aimed to explore the differences of line graph interpretation skills across three distinct groups: first-year pre-service teachers (PSTs), third-year PSTs, and in-service teachers (ISTs). The results showed a progression in line graph comprehension from first-year PSTs to

ISTs, but no significant improvement between the first- and third-year PSTs. The findings underscore the importance of practical teaching experience in enhancing graph interpretation skills, although the robustness of this knowledge is questionable as could be inferred by the relatively low proportion of correct answers from the ISTs for some of the items. The lack of significant differences between first- and third-year PSTs raises questions about the effectiveness of the current teacher education curriculum in fostering graph comprehension skills. Despite their exposure to increasingly advanced mathematical content, third-year PSTs did not show marked improvements over their first-year counterparts. This suggests that the existing curriculum may not be adequately addressing the specific pedagogical strategies or content knowledge necessary for developing strong graph interpretation skills. One possibility is that while the curriculum provides mathematical and statistical content, it may not focus sufficiently on the graphical literacy aspects that are crucial for teaching and interpreting data in the classroom. In the furtherance of teacher education programs, it may be beneficial to integrate more targeted instruction on graph interpretation and analysis, emphasising real-world applications of graphing skills (Friel et al., 2001; Shah & Hoeffner, 2002).

Importantly, this study brings into focus some insightful features of linear speed-time graphs, demonstrating why graph comprehension embedded in context can be demanding. Although we did not conduct interviews, yet the questionnaire's design —focusing on various interpretations—allow us to offer potential explanations for deductions made by participants. In general, there is an intuitive tendency to make direct inferences from the graphic display without moving to the next level of thinking as could be inferred when the respondents had to read beyond the data. For instance, Question 3 posits that Car 1 and Car 2 will meet if they travel at the same speed for the same duration. However, the fact that their paths intersect on the graph in Figure 1 does not imply a physical meeting. Thus, an additional level of deduction is required to realise that the point of intersection shows the time at which the two cars have the same speed, and this does not imply that they meet physically. A numerical example serves to instantiate this relationship. For instance, after 10 mins, both car A car B may have a speed of 60 km/h but that does not mean they would have covered the same distance. Thus, a common misinterpretation relates to the point of intersection, mistakenly perceived as physical locations, rather than understanding them within the context of relationships like speed and time, where location is irrelevant. This observation also rejoins what Kosslyn (1985) referred to as visual perception (the visual image of a graph) and graphic cognition (converting a visual image into meaningful information). The teacher education program of the current sample of teachers may not have adequately addressed this important component of teacher knowledge, a point also supported by Jacobbe & Horton (2010) who argued that lack of exposure to content influences graph comprehension.

Similarly, the low proportion of correct answers in Question 19 (Car 1 had a steeper route than Car 2) can be explained by the direct intuitive association that the respondents may have made from the visual appearance of the line graph of car 1 being higher than that of car 2. Furthermore, the research corroborates earlier studies which found that not only students but also teachers frequently interpret graphs as literal representations of events rather than abstract quantitative data (Bell & Janvier, 1981; Leinhardt et al., 1990; Patahuddin & Lowrie, 2019). This misinterpretation underscores the need for educational strategies that enhance the understanding and interpretation of context-based graphical data among teachers, improving their ability to convey abstract concepts effectively.

The findings from this study not only inform improvements in teacher training but also lay the groundwork for future research aimed at enhancing the analytical competencies essential in our data-driven world. However, given the study's focus on a specific graphical task and a regional participant pool, further research involving a broader range of tasks and demographics is necessary. Expanding the scope of research could provide a more comprehensive understanding of how different educational systems and cultural contexts influence graph interpretation skills, contributing to the development of effective pedagogical strategies. While this study offers insights into graph interpretation across teaching career stages, its cross-sectional design limits the ability to examine individual development over time or identify factors behind group differences. Future studies using qualitative methods, such as interviews, could help explain the lack of progression observed in teacher education.

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