Exploring Attentive Behavior While Reading Mathematics Textbooks

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Textbooks remain central in undergraduate STEM education, yet little is known about how readers distribute attention across the diverse elements of extended mathematical texts. This study investigates how mathematics majors, non-mathematics STEM faculty, and non-math majors read a four-page excerpt from a standard calculus textbook. Using eye-tracking, we compared participants' attention to expository prose, worked examples, figures, and a highlighted formula. Exploratory analyses suggested differences between the groups' distributions of attention. However, a compositional data analysis did not reveal statistically significant group-level differences. These findings point to the importance of disciplinary literacy frameworks in interpreting attention patterns and raise questions about how readers' identities shape engagement with mathematics texts.

Keywords: Mathematics Textbooks, Reading, Didactical Disciplinary Literacy, Eye-Tracking

In STEM education, pedagogical texts, such as textbooks, are central curricular resources; they provide a basis for content and sequencing as well as serving as learning resources for students. In conjunction with increased interest in pedagogical formats such as "flipped" classes (e.g., Maxson & Szaniszlo, 2015), educators and researchers have highlighted the "need for greater attention to reading in mathematics instruction" (Doerr & Temple, 2016, p. 6).

Despite the central role played by textbooks, detailed evidence about how readers distribute attention across extended expository passages in pedagogical texts remains limited. Eye-tracking has been used extensively to study reading and learning across educational contexts (Holmqvist et al., 2011; Rayner, 1998), and mathematics education researchers have begun to apply it to understand students' attentive practices (e.g., MacKay et al., 2025; Zhang et al., 2025). Still, there are relatively few studies that examine how readers engage with longer instructional texts.

The goal of the present study is to extend this line of work by investigating how different groups of readers allocate their visual attention when reading an excerpt from a calculus textbook. Building on prior research contrasting students' and experts' engagement with calculus texts (e.g., Shepherd & van de Sande, 2014; Weinberg et al., 2023; Wiesner et al., 2020), we examine how mathematics majors, non-math majors with calculus experience, and non-mathematics STEM faculty attend to prose, worked examples, figures, and highlighted equations in a common calculus text (Stewart, 2016). In particular, we ask how attention patterns vary across these groups, and how these patterns can be interpreted in relation to readers' disciplinary and didactical literacy practices.

Literature Review

Reading in Educational Contexts

Pedagogical texts are situated within disciplinary genres with conventions that require readers to engage in particular reading practices (e.g., Rezat, 2006; Rezat & Rezat, 2017). Mathematics textbooks are highly multimodal: they integrate prose, formal definitions, theorems, examples, and diagrams (Fan, et al., 2013; Lemke, 1998; O'Halloran, 2005; Pepin & Haggarty, 2001). Prior research has shown that novices tend to read superficially, focus on worked examples, and under-utilize expository text (e.g., Mesa, 2010; Randahl, 2012; Shepherd et al., 2012; Shepherd & van de Sande, 2014; Weinberg et al., 2012). While design elements like boxed formulas or diagrams can scaffold learning (Lai et al., 2012), they may also constrain attention to salient but less integrative features.

Some of these results have been investigated using eye-tracking (ET) methods. ET measures like fixation times and scan paths have provided insight into how readers select and integrate multimodal information (e.g., Coskun & Cagiltay, 2022; Lai et al., 2013; Liu & Cui, 2025), although most of this work has been descriptive rather than theoretically grounded. Studies suggest that readers selectively attend to various text components (e.g., diagrams or highlighted equations), and that this varies by reader characteristics (knowledge, motivation, and disciplinary identity) and task context (e.g., Drexler et al., 2019; Hochpöchler et al., 2013; Ögren et al., 2017; Panse et al., 2018; Schnotz & Wagner, 2018; Schnotz et al., 2014; Tóthová & Rusek, 2022). Such findings underscore that reading mathematics texts is not uniform between readers, and that readers' attention is shaped by knowledge, task demands, and textual design.

Disciplinary and Didactical Disciplinary Literacy

The perspective of disciplinary literacy was introduced to examine how reading and writing are tied to disciplinary values, norms, and reasoning practices (Moje, 2007; Shanahan & Shanahan, 2008; 2012). Disciplinary literacy is socially situated within intellectual communities (Boaler, 2002; Bishop, 2012; Moje & Luke, 2009). Thus, knowing mathematical content cannot be separated from knowing how to engage with the texts where that content resides.

Mathematics texts encode conciseness, formal justification, and multimodal coordination (Morgan, 1998; Doerr & Temple, 2016; Lee & Spratley, 2010); and mathematicians' disciplinary literacy complements these features. In a comparison between mathematicians, chemists, and historians, Shanahan et al. (2011) found that mathematicians use the structure of the text to support understanding; reconcile the text with their own knowledge to focus attention; emphasize accuracy; view graphics as an integral component of the prose itself; and engage in intensive rereading. In contrast, historians viewed graphics as potentially ancillary to the text; chemists demonstrated more subtle differences, such as viewing graphics as alternative forms of overlapping information.

Textbooks, which are "pedagogically prepared for classroom use" (Kling et al., 2017, p. 2), differ from research texts in both style and function (Fauvel, 1988; Richards, 2002). Weinberg et al. (2023) extended disciplinary literacy to account for texts specifically written for instructional purposes by introducing the concept of didactical disciplinary literacy (DDL), which involves practices such as framing the text as a product of authors; referring to instructional purpose; attending to teaching-related structures in the text; and expressions of authority in teaching and learning (Weinberg et al., 2023). Readers' meaning making depends on both disciplinary background and sensitivity to pedagogical design (Wiesner et al., 2020; Fulmer et al., 2022).

Gaps and Research Question

Comparative ET research in mathematics rarely juxtaposes novices and experts, despite evidence from other fields (Harsh et al., 2019) that expertise mediates attention. Furthermore, ET work often lacks integration with disciplinary literacy frameworks, limiting interpretation of gaze measures (Andrä et al., 2020). In addition, the intersection of disciplinary literacy, DDL, and attention allocation remains underexplored, especially in the context of mathematics texts. The present study addresses these gaps by examining how STEM faculty, mathematics majors, and non-majors allocate attention to expository text, figures, examples, and highlighted equations.

Our research question is: How is a reader's distribution of attention across different types of text (examples, text, figures, and equations) in a standard calculus textbook excerpt related to their positioning in the mathematics and school community?

Theoretical Framework

The core of our framework is the idea that readers actively select components of the text to focus on as they read, that this selection is guided by disciplinary norms and their own content knowledge, and that their eye fixations reflect their attention.

Reading Attention and Eye Movements

Researchers in mathematics education have increasingly begun to use eye-tracking to study how readers attend to texts, solve problems, and engage with multimodal representations (Schindler & Lilienthal, 2019). As Schindler et al. (2025) point out, most eye-tracking work operates based on the eye–mind hypothesis (Just & Carpenter, 1980; Rayner, 1998), which proposes a positive connection between visual fixations and cognitive attention, and in which, as König et al. (2016) note, gaze patterns are seen as indicators of higher mental processes such as perception, memory, problem solving, and abstract reasoning.

Gaze data are not inherently self-explanatory. For example, several scholars (e.g., Andrá et al., 2015; Hartmann et al., 2015; Holmqvist et al., 2011; Jacob & Karn, 2003) have proposed that readers' cognitive behavior might not match what their eyes are fixated upon, and some research (e.g., Schindler & Lilienthal, 2019; Thomaneck et al., 2022) has demonstrated evidence of such mismatches. Despite these limitations, numerous researchers (e.g., Alemdag & Cagiltay, 2018; Deubel & Schneider, 1996; Remington, 1980; Scheiter & Eitel, 2017; Schindler & Lilienthal, 2019; Thomaneck et al., 2022; van Gog et al., 2014; Wang et al., 2019) have found that eye movements are generally linked to attentional foci.

Disciplinary and Didactical Disciplinary Literacy

As Barton and Hamilton (2000) described, literacy practices are "the link between the activities of reading and writing and the social structures in which they are embedded" (p. 7). Disciplinary literacy refers to the specialized ways of reading, writing, and reasoning that are characteristic of each academic field (Fang & Schleppegrell, 2010; Rainey & Moje, 2012). In mathematics, this entails precision with notation, logical structure, coordination of representations (symbolic, graphical, verbal), and orientation toward proof and generalization (Morgan, 1998; O'Halloran, 2005; Rezat & Rezat, 2017). Readers engage not just with words and symbols but with the epistemological norms and values of mathematics itself.

Didactical disciplinary literacy (DDL) extends disciplinary literacy to the context of instructional texts (Wiesner et al., 2020; Weinberg et al., 2023). It involves readers' ability to recognize and interpret instructional scaffolds such as boxed definitions and worked examples; critique texts as instructional artifacts; and navigate their positionality within institutional settings and norms, among other skills and habits. DDL highlights how readers' practices are simultaneously disciplinary, didactical, and situated within relations of power.

Methods

Participants and Materials

The study is structured as a comparison between three groups expected to bring a range of literacy practices and content knowledge to the reading experience. The first group consisted of five students who had declared either a major or minor in mathematics and had completed at least the first two semesters of college-level calculus and a semester of linear algebra with a grade of at least C-; we hypothesized that students in this group had developed and refined literacy practices for reading didactical mathematics texts and would also have sufficient knowledge to learn new calculus concepts by reading a textbook excerpt.

The second group consisted of five students who had completed a single college-level calculus course with a grade of at least C- in the previous semester. We hypothesized that these students had developed sufficient calculus knowledge to learn a new concept but were less likely to have developed sophisticated DDL practices for mathematics.

The third group comprised five faculty members (biology (2), chemistry, environmental science, and physics), all with PhDs, at least four years of undergraduate teaching experience, and active research agendas. As a result, they were skilled in interpreting disciplinary texts and using textbooks pedagogically. All had taken calculus; but, except for the physicist, none had used calculus in over a decade. We expected the group to have less calculus knowledge than the student groups, but disciplinary literacy practices similar to those of mathematicians (as supported by the findings of Shanahan et al., 2011).

Participants were recruited via email from lists of all students and faculty who met the above criteria. Participants were selected from among the respondents based on whether they continued to respond to scheduling emails and their availability during scheduled interview time slots.

We sought to have all participants read for the same purpose—namely, to learn a new concept. We selected the section "Newton's Method" from a widely used calculus textbook (Stewart, 2016). This four-page excerpt included expository prose, a formula (presented inside a blue box) for obtaining the $n+1^{st}$ approximation from the n^{th} approximation of the root of a polynomial, three worked examples, and seven figures. At the beginning of the reading session, all participants were asked about their familiarity with Newton's Method, and all indicated they were not familiar with the concept.

Data Collection

During each interview, the textbook excerpt was displayed on a computer monitor, and the participant was able to navigate between the pages using the computer keyboard. Participants were asked to read the excerpt "to learn about the concept of Newton's method" at their own pace, while the interviewer worked independently at a separate desk. They were provided with a pen and paper and told they could take notes as they read. The participant's eye movement was recorded with a Tobii X2-60 eye tracker mounted below the monitor and calibrated according to manufacturer guidelines (Tobiipro, 2019).

AOI Construction and Data Processing

We created a rectangular Area of Interest (AOI) around each section of expository prose, figure, example, and the formula in the blue box. The AOIs were grouped by type: blue box formula, example, figure, or text. This choice of grouping was made to reflect the ways in which mathematics disciplinary literacy practices differ from those in other disciplines by tightly integrating the interpretation of expository prose, graphics, and formulas, with the goal of enabling us to (1) explore ways in which these elements might be approached by the different participant groups and (2) the extent to which the didactical nature of the text might lead to different attentive patterns.

We restricted the set of eye movements to fixations, created a variable to indicate which AOI each fixation was contained in, and then computing the total duration (in seconds) for which each participant had fixations within each AOI. We then computed the total fixation duration for each type of AOI for each participant. One participant (one of the biology faculty members) had long stretches with no valid fixation data, so we omitted their data from our analysis.

Results

Participants distributed their attention across the different types of text in a wide variety of ways. For example, one non-math major spent approximately 60% of their time looking at the examples and 20% in each of text and figures, while one math major spent approximately 55% of their time looking at the figures, with 20% looking at the examples and 25% at the text.

The percentages for the blue box formula were uniformly small (approximately 2% among all participants). Thus, we examined the distributions of the other AOI types using the ternary plot shown in Figure 1. In this plot, the three colors (red, green, and blue) indicate data from the three groups (MM, NMF, and NMM). Each group's dots are connected by a convex hull, and the large black dots are the hull centroids, which represent group averages. From the centroids, we can see that the math majors tended to spend a larger proportion of their time reading the expository text; the non-math majors tended to spend a larger proportion of their time looking at the examples; and the non-math faculty tended to spend a larger proportion of their time examining the figures. Although there is some overlap between the hulls, visual inspection suggests that the three groups exhibit relatively distinct distributions of attention.

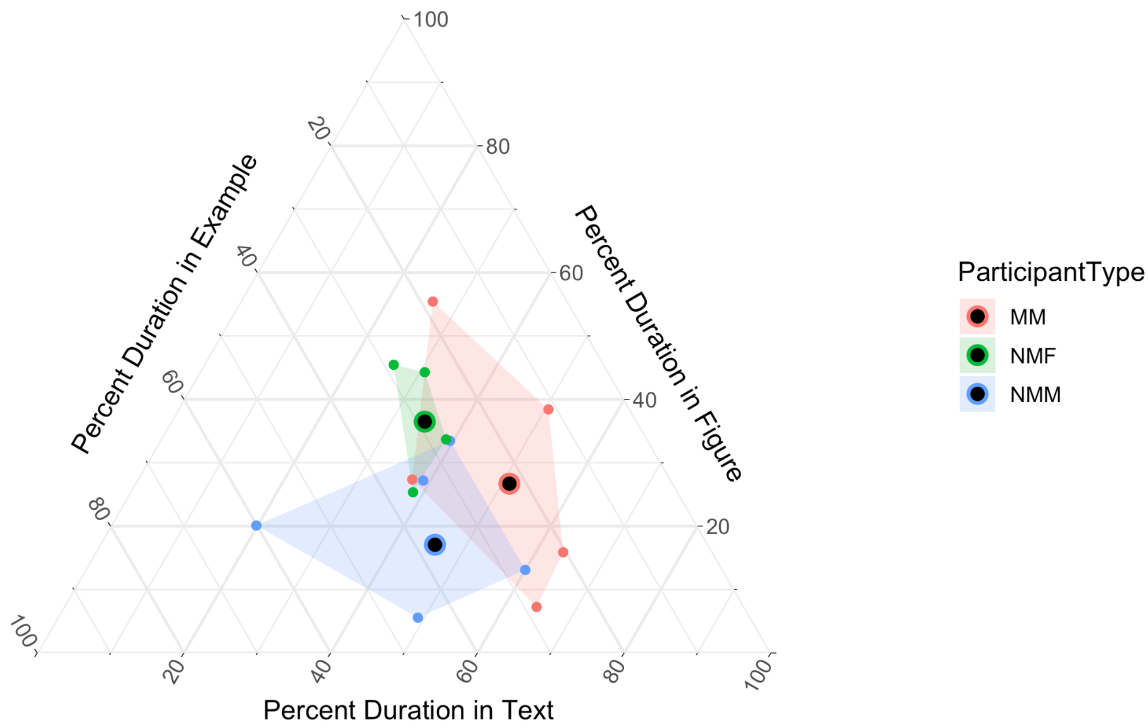

Figure 1. Ternary plot of participants' proportional durations in the example, figure, and text

Within these global patterns, however, there was a relatively considerable amount of variation among the participants within the MM and NMM groups compared to the NMM group, as demonstrated by the large areas of the hulls. In addition, the separation between the three hulls does not occur along a single axis, suggesting that between-group differences might not align with the three AOI types.

Compositional Data Analysis

Our data are non-negative and multivariate, with values that only carry relative meaning and, within each individual and group, must sum to a fixed value (in this case, 100%). This constant-sum constraint violates assumptions of independence in standard statistical methods. Thus, compositional data analysis, which uses logarithms of ratios of values, is the most appropriate statistical tool.

To conduct this analysis, we began by transforming our data using an orthonormal basis of log ratios of parts, which maps the data into a set of orthogonal components and eliminates collinearity. This isometric log-ratio (ILR) transformation is: $ilr(x) \coloneqq V^t clr(x)$, where $clr(x)$ is the centered log ratio that expresses each component relative to the geometric mean of all parts, and V is an orthonormal basis of the clr plane. We then compared the resulting three (now independent) ILR coordinates across groups (MM, NMM, NMF) using a permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001). The analysis, based on Euclidean distances with 999 permutations, indicated that participant type did not significantly predict variation in the duration data ($F(2, 11) = 0.89$, $R^2 = 0.14$, $p = 0.50$). Thus, when considering all three ILR coordinates jointly, our data do not provide evidence of a significant overall difference in the distribution of attention across the stimulus types between groups.

To follow up this non-significant result, we conducted a principal component analysis (PCA) on the CLR-transformed duration data to investigate the potential for more complex relationships between factors. Four components were extracted, with PC1 accounting for 65.1% of the variance and PC2 for 18.9% of the variance. Loadings indicated that blue box (0.61) and figure (−0.79) duration loaded strongly on PC1, whereas example (0.53) and text (0.45) loaded on PC2. A plot of the first two components is shown in Figure 2.

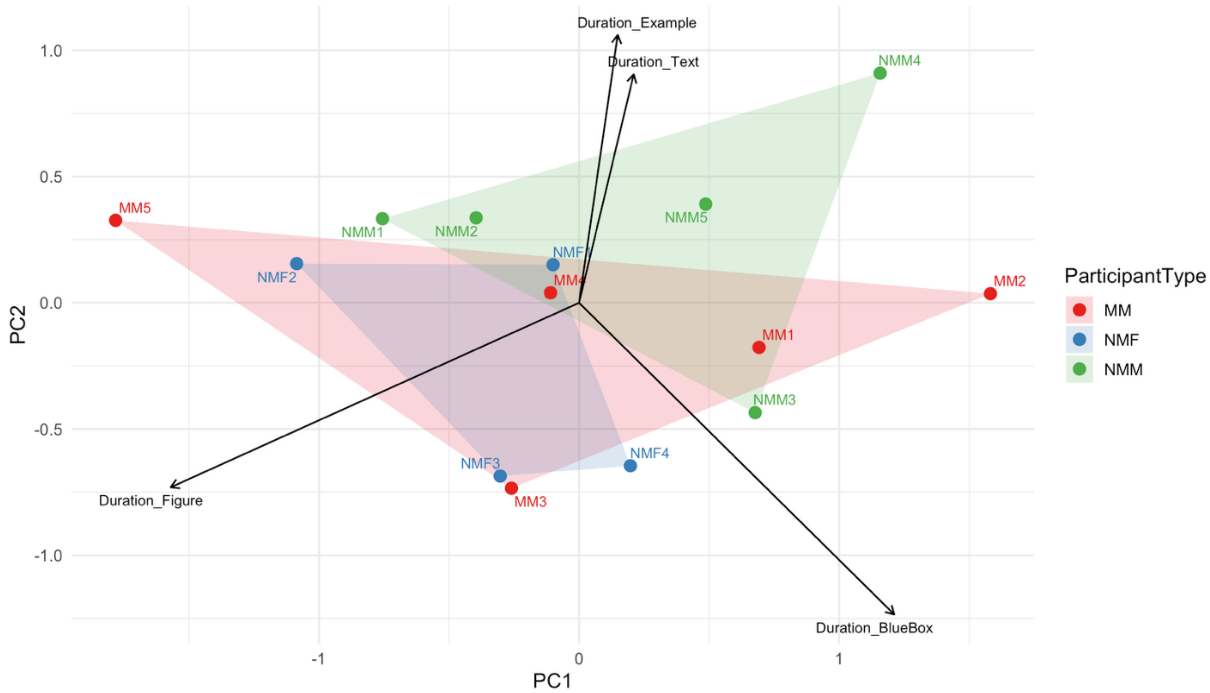

Figure 2. PCA biplot of duration variables.

In this plot, the arrows represent the contribution of each stimulus type to the principal components; these arrows suggest that the figure and blue box components most strongly influence PC1, while example and text primarily play a role in PC2.

Each point in the graph represents one participant's score along the PC1 and PC2 axes. The points are connected by colored convex hulls to highlight similarities and differences within and between groups of participants. In the green hull (NMM), four of five points had relatively higher PCA scores along PC2. The blue (NMF) and red (MM) hulls occupy roughly the same range along the PC2 axis, suggesting a similar balance between text and example durations. However, the MM hull suggests that some MM participants spent relatively more or less time on blue box and figure compared to others, whereas the clustering of NMF along PC1 indicates more uniformity in their distribution of blue box and figure attention. However, these group-level interpretations are exploratory and not inferential.

Discussion

The initial EDA revealed differences in how the participant groups allocated their attention across types of text. The faculty members distributed their attention roughly evenly among the example, figure, and text, while the math majors tended to focus on the expository prose and the non-math majors focused on the examples. One explanation for these patterns could be the participants' disciplinary literacy practices. The faculty members were all scientists, and one disciplinary literacy practice in science is to view different text elements as alternative forms of overlapping information (Shanahan et al, 2011); this might have led faculty members to attend equally to the different types of text. Similarly, the math majors might have focused on the expository text to closely read the derivation of Newton's Method because understanding derivations is an essential mathematical practice. In contrast, the non-math majors' focus on the examples could be interpreted from a perspective of what it means to know mathematics, in which understanding a concept is viewed as equivalent to being able to perform a procedure.

The perspective of didactical disciplinary literacy provides a slightly different set of explanations for the participants' distribution of attention. One DDL practice involves attending to the textbook authors' instructional purpose. In this textbook excerpt, the figures played the role of providing an intuitive explanation of more formal aspects of the text. The faculty members might have recognized this purpose and, consequently, focused their attention on the figures, while the math majors' attention was still guided by the disciplinary focus on the formal symbolic derivation. In contrast, the non-math majors' focus on the examples could be explained by their identity as students and their anticipation of being asked to solve similar problems.

The permutation MANOVA did not reveal a statistically significant difference between the groups' distribution of attention. One explanation for this is that there are no significant differences between the groups. Another possible explanation is that there is significant variation within each group, and the small sample size didn't provide sufficient statistical power to identify the differences. The PCA biplot suggests yet another explanation: There might be differences between the groups, but these differences exist on more complex combinations of groups of variables, such as contrasting figure + formula with text + examples.

By examining how different reader populations allocate attention across types of text, the present study offers one of the first attempts to link measurable patterns of attention with theoretically grounded models of literacy. Future work could include combining AOIs along other dimensions, such as mathematical content or pedagogical purpose, to further examine relationships between DL, DDL, and participants' attentional distribution.

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