Experiences of Students with Dyslexia in Undergraduate Mathematics: Cognitive Challenges and Navigational Strategies

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How do undergraduate students with reading difficulties engage in mathematics – a symbolically dense, text-heavy subject? This study analyzes reflections from seven undergraduate STEM students with dyslexia on their approaches to mathematical learning and problem-solving. Our findings indicate that students experienced multiple dyslexia-related cognitive challenges, including processing, organizing, and manipulating conceptual information. To combat these challenges, students reported strategies to structure information visually and minimize the cognitive burden of the tasks. These results offer an initial account of how students with dyslexia approach and experience undergraduate mathematics.

Keywords: dyslexia, working memory, cognition, visualization, student experiences

Dyslexia can be characterized by measurable difficulties with phonological processing, affecting reading and writing skills, and is often unexpected in comparison to other academic abilities (International Dyslexia Association, 2025; Lyon et al., 2003). Dyslexia is estimated to affect between three and seven percent of the population (Wagner et al., 2020), and comorbidity with other neurodevelopmental differences is high (Moll et al., 2020). In the past two decades, enrollment of post-secondary students with specific learning differences has increased dramatically, with dyslexic students constituting the largest subgroup (Richardson, 2021).

Despite this prevalence, little is known about how students with dyslexia understand, learn, and do undergraduate mathematics. Research on undergraduate students with dyslexia (USDs) tends to focus on study skills (e.g., Andreassen et al., 2017; Mortimore & Crozier, 2006), general academic challenges and strategies (e.g., Knight et al., 2024; MacCullagh et al., 2016; Richardson, 2021), or identity and perception (e.g., Griffin & Pollak, 2009; Pino & Mortari, 2014). Language-based difficulties (such as reading, memorization, note-taking, organizing work, and communication) and cognitive difficulties (such as concentration, executive functioning, retaining the meaning of texts, and processing sequential information) are also explored in the literature (Klein, 1993; Mortimore & Crozier, 2006; Riddick et al., 1997; Smith-Spark et al., 2016). These cognitive difficulties largely relate to working memory (WM) – a mental workspace of limited capacity for the temporary storage and manipulation of information (Baddeley, 2000; Baddeley & Hitch; 1974) – sometimes used as a framework for understanding specific learning differences (e.g., Jeffries & Everatt, 2004; Swanson, 2020; Swanson & Siegel, 2001).

For mathematics specifically, the discussion often focuses on foundational or lower-level mathematical issues faced by USDs, such as problems recognizing symbols, notation, or "following a sequence of steps or actions" (Searle & Sivalingam, 2004, p. 5). Developing learning support resources and recommendations for USDs has also been discussed extensively (Perkin & Croft, 2007; Trott, 2003a, 2003b). Our study highlights, in their own words, the cognitive challenges and navigational strategies USDs report when engaging in higher-level mathematical tasks (such as proof production and comprehension) and when reflecting on undergraduate mathematics learning. In doing so, we expand and develop the findings of Perkin's engineering case studies (Perkin, 2004). As Lambert and Harriss (2022) did for research mathematicians with dyslexia, we aim to develop an emergent account of USDs' mathematical experiences from an 'insider perspective'. Our primary research questions are:

RQ1: *What cognitive challenges do USDs experience in mathematics courses?*

RQ2: *What strategies do they implement to navigate these cognitive challenges?*

Theoretical Framework

We frame our study within the theory of neurodiversity, which conceptualizes neurological differences (and dyslexia in particular) as natural and valuable variations in human cognition. Originally developed in the autistic community (Robertson & Ne'eman, 2008) and recently adopted in studies on dyslexia (e.g., Lambert & Harriss, 2022), neurodiversity posits that cognitive differences are a natural part of human diversity and can carry both affordances and challenges. This perspective stands in contrast to the traditional *medical model* (also called the *deficit model*) of disability, which depicts dyslexia primarily in terms of individual impairments.

Through this theoretical lens, we view challenges that USDs experience in undergraduate courses not as evidence of deficiency, but as reflections of how students with dyslexia interact with cognitively demanding mathematical tasks and learning environments, which oftentimes privilege particular forms of information processing. At the same time, this framework highlights the strategies that USDs develop to navigate these challenges as distinctive strengths they bring to undergraduate mathematics. We follow an insider perspective (Lambert & Harriss, 2022; Lambert et al., 2019) by studying USDs' own reflections on their perceived challenges and navigating strategies, positioning their voices as central to understanding both barriers and affordances in mathematical learning.

Methods

The data reported here are part of a larger study aimed at understanding how USDs use hand gestures during cognitively demanding mathematical tasks. We recruited seven participants who were professionally diagnosed with dyslexia, representing a range of STEM majors but all enrolled in undergraduate mathematics courses: Aoife, Aran, Caitlin, Eibhinn, Maeve, Sean, and Siobhan (all pseudonyms).

Each student completed an online survey, then participated in a task-based interview (Interview #1) and a stimulated recall interview (SRI; Interview #2). The survey asked participants to (1) describe their experiences learning mathematics at university, including classroom interactions and assessments, (2) explain how dyslexia had impacted their learning of mathematics across school and university contexts, and (3) identify strategies or coping mechanisms they use for managing mathematical tasks. These survey responses provided descriptive context for each participant and were used to facilitate discussion in Interview #2.

The task-based interview invited students to solve mathematical problems while verbalizing their reasoning, which provided insight into the cognitive and linguistic processes they engaged in while problem-solving. The tasks reported on in this study are summarized in Table 1, below. Because of the design of the larger study, participants were not given access to a pencil and paper while working on these tasks. The SRIs followed several days after Interview #1; During the SRIs, students viewed selected video clips of their own problem-solving and reflected on the challenges they faced and strategies they employed. Building on these reflections, the interviewer also asked participants about dyslexia-related difficulties they experienced when navigating undergraduate mathematics courses, drawing on their earlier survey responses.

Table 1. Summary of Interview #1 tasks.

Task name and source	Task description
Triangle Task (Nathan et al., 2014)	True or False? The sum of the lengths of two sides of a triangle is always greater than the length of the third side. Provide proof for your claim.
Gear Task (Nathan et al., 2014)	An unknown number of gears is connected in a chain. You know what direction the first gear turns, how could you figure out what direction the last gear turns? Provide a justification as to why your answer is true.
Two-Color Theorem (Kokushkin, 2024)	Read and understand the proof of the statement: "$n \geq 1$ circles are given in the plane. They divide the plane into regions. It is possible to color the plane using two colors, so that no two regions with a common boundary line are assigned the same color."

All interviews were audio-recorded and transcribed verbatim. Survey responses and interview transcripts were analyzed using the constant comparative method (Glaser & Strauss, 1967). We first coded our data to identify specific challenges and navigating strategies. These codes were further combined into categories, which served as the foundation for latent themes that captured shared experiences across participants (Braun & Clarke, 2006). To enhance trustworthiness, two researchers independently coded an initial subset of transcripts, resolved discrepancies through discussion, and applied the refined scheme to the full dataset. In the excerpts presented here, emphasis added by the authors is indicated through underlining.

Results

We report on four themes that provide insight into our research questions. We remind the reader that in our experimental setting, participants were required to complete all activities mentally. This experience was used to prompt students to reflect on their daily struggles processing (i.e., understanding, structuring, and manipulating) mathematical information. We do not claim these challenges and strategies are unique to USDs; however, we believe it is important to recognize how such challenges are encountered and addressed by these students.

Challenges

Many of the challenges our participants reported can be understood as a difficulty (A) with organizing and structuring written and verbal information, and (B) with holding and manipulating information in their WM.

Organizing and structuring information. Our participants reported persistent obstacles to engaging in undergraduate mathematics, centering on difficulties in internally (re)organizing written and verbal information. Describing the experiment conditions, Aran found it "hindering" not being able to write, as writing "helps [him] keep all [his] thoughts in place." Siobhan found it notably difficult to keep her train of thought organized and "in line" when answering mathematical questions. Similarly, Sean found it "much harder" to tackle the mathematical problems verbally, as "[his] ideas get jammed with one another, and [he] lose[s] [his] train of thought." He further elaborated: "When I'm thinking it in my head…it's all just black and white. So in other words, you know, it all just gets kind of mixed up within one another."

To articulate their difficulties in processing written and verbal content, participants often used the language of "visualization" – forming mental images to help recognize and structure relevant details into a coherent whole. Sean expressed a need to be provided "some sort of <u>diagram</u> or something that's not just fully word based" – because "if there's nothing to visualize, you have to be your own person to visualize it." Eibhinn found it challenging "trying to <u>picture</u>

the situation from what [she] was reading" while Caitlin similarly remarked: "It's very hard when I can't draw it out, because I feel like I'm a very visual…I need to see how it's actually happening." When asked "what was difficult about these tasks?", Siobhan indicated it was:

> "…hard to like, visualize and not being able to write anything down, it's just like coming up with what to say just off the tip of the tongue, usually I have to like, write down my thoughts, or, like, organize them in a way that's sometimes hard to do that on my head."

Along similar lines, participants sometimes expressed frustration or dissatisfaction when they were unable to clearly 'see' how information is assembled: Siobhan shared how "textbooks… sometimes give an image, but it's all combined. Or if they're, like, telling you to graph things, it's the whole graph at the very end" – not showing "the process being done" from the presented information. Likewise, Sean expressed dislike "when someone gives [him] just a big paragraph of an essay for a math problem, because [he] can't visualize that."

WM challenges. Participants also reported difficulties with activities that placed demands on their ability to simultaneously hold and manipulate information – highlighting WM as a potential source of struggle. For example, reviewing the gear task, Sean commented:

> "I couldn't really see how it would turn, because I could imagine, you know, the gears all lined up, right, but seeing them all go like, in motion with one another, that's a little too much that I can't think in my head."

While Maeve described visualization as "really easy" for her – even saying "I can take things in my mind and twist them around…like, on SolidWorks" – she struggled when trying to coordinate several objects simultaneously, an activity that places greater demands on her WM:

> "…I can never visualize that [interlocking gears turning], like, I can never figure out which way it's going…I always get mixed up with the way that the arrows are spinning… when [the gears], like, attach, in my mind, they're going the same direction, even though I know they're not."

In the context of the Two-Color theorem, Eibhinn struggled and ultimately failed to grasp the inductive step in the proof. In recounting her struggle, she distinguished between the "easy to picture" static arrangement of k colored circles (the inductive hypothesis), and the "hard to picture" inductive step, which involves adding one more circle and recoloring. Failing to mentally operate on her concept image in the inductive step suggests a difficulty in navigating the cognitive load for the task, and an overtaxing of her WM. On a more general level, Sean explained he keeps a mental "whiteboard" of task-relevant information, that he updates while working through a problem:

> "I would have, like a whiteboard of a thing in my mind, and I'm just drawing this out and just combining one with another and seeing where that goes…for me, I really just need to visualize it. And could be because I can't read well and…it takes me a longer time to comprehend the writing in general."

Sean is aware this strategy has its limitations, adding "the hard thing about it [is] that there's only so much room you could have on there, and when you start throwing at me more and more stuff, I might lose track of certain things." Our participants' reflections suggest that it was not only the conceptual content, but the cognitive load in simultaneously visualizing and manipulating task-relevant elements, which they felt posed a significant challenge to them.

Strategies

Participants conveyed a number of 'coping mechanisms' or 'strategies' to offset the impact of dyslexia on their mathematical learning. We report on these strategies below, organized to complement the challenges identified in the previous section.

Organizing and structuring information. A core tool for structuring thoughts and answers (mentioned by most of the participants) was writing. Aran explained that "writing all these things down, helps you remember them, and helps [him] keep all [his] thoughts in place." Similarly, Sean expressed his desire for "just a little piece of paper or something to write it all out, or, you know, put one idea with another" as this would have aided him to "answer the question more fluently." Writing also featured in the routine some students were taught to help them tackle problems: Maeve reported she systematically identifies her "given, assume, and find" in a question, to ensure she does not overlook important information.

The repetition of information through writing also gave students confidence they had correctly understood information from the presented text. Maeve, referencing exam questions, explained: "I'll write *m* is equal to one, even though it's in the question. Just having it out there, like is, like, just reassurance that I know *m* is equal to one." Echoing this, Aran described how writing gives him confidence, sharing: "I know I already got this in the problem. I trust myself. I wrote this things down [sic]." For Interview #1, he reported using his hands "as [his] pencil" to mentally underline text and highlight important information. Aran felt that "it's not permanent, but it would help [him] understand, at least at that point, what…[he's] trying to understand."

Students used their hands not only as tools to focus their attention, but also to organize abstract aspects of their mathematical work. While discussing the triangle task, Aran explained he gestured to give himself "an image of what [he] was trying to do" and to "visualize what's happening" – to understand the task and to marshal his approach to its solution. To keep her thoughts "in line", Siobhan pointed to parts of the table before her, left to right, as she solved the gear task. She clarified she was "categorizing" her thoughts, and giving herself a visual representation of spatially organized "thought process[es]" to structure her verbal answer. Eibhinn and Maeve also used gestures to facilitate communication with the Interviewer, with Maeve clarifying "[she] was trying to draw with [her] hands that time, not for [her] sake, but to convey what was happening in [her] brain."

All of our participants identified visualization as a key strategy for attempting the mathematics tasks – with Sean stating "visualizing it has always been [his] best friend in trying to do any math problem". In her SRI, Aoife suggested that, to her, the underlying meaning of mathematical information is expressed visually, and not symbolically:

> "I think it just makes a lot more sense that way, as an image. Like, in my mind, I can kind of think about it that way a lot better than like the numbers or like the math or equation type thing like that…I can solve it, but it doesn't really mean that much to me. But I think I like images and pictures, I think that's how I think."

Navigating cognitive load. Our participants described a range of strategies to help them retain and manipulate information in their WM. These included strategies of selective attention while encoding information, active rehearsal for retention, and mechanisms for offloading information. In what follows, we elaborate on these strategies for navigating cognitive load.

Given our participants' persistent challenge in processing written text, selective attention emerged as one of the key encoding strategies. Broadly, this strategy can be summarized as deliberate actions for reducing redundant processing by focusing on the most relevant or the most important pieces of information. Several participants described underlining key pieces of text in problem statements or coloring mathematical expressions to minimize overlooking critical details. Sean, for example, shared: "When I take down my notes, especially for math, I like to color things in…when I'm thinking it in my head…it's all just black and white."

Some students described strategies for reformatting written information in a more cognitively accessible way, which, as they reported, was especially helpful in mathematics. Maeve, for instance, sometimes replaced technical terminology with simpler terms: "By switching the element with an easier-to-read element, I'm able to focus more on the math than the reading of the problem, while still understanding the context." Similarly, Siobhan noted that symbolic expressions were easier to process when visually rearranged: "When you're doing a division problem, if it's like, *p* minus one divided by *n* minus one, I would understand it better if I just saw it written out vertically, not just horizontally on the page."

Another common strategy students described involved re-reading written text, or 'rehearsing' information. These practices were referenced as an efficient way to retain information, especially when writing is not available. Eibhinn reported using noise-dampening headphones during exams, as they allow her to "hear [herself] say the stuff a little bit more" clearly in her head. Aran shared he needed to re-read "[j]ust to get the information out" because he would "forget it…not understand it fully, or mess it up a little bit." Sean re-read text to help him connect information at the end of a paragraph to information he was given at the beginning, explaining:

> "I always try to relate this new information to what we talked about before, so that that original information I got in the beginning doesn't get lost. So I'm always trying to go back and just trying to fill in these gaps that the problem is slowly giving me."

Most participants described strategies for offloading encoded information to alleviate demands on WM. For example, Aran explained that when working on a mathematical problem, he typically writes down everything he considers "useful" before attempting a solution. In a similar vein, Aoife emphasized the importance of recording information, as "making it out of [her] head and on the page" prevents her from becoming overwhelmed and "mixed up." Several participants reflected on how gestures also supported their WM when writing was restricted. During his SRI, Aran explained that hand motions helped him to make progress on the gear task, as "moving [his] hands helps [him] actually move the gears in [his] head," and allows him to "remember, in a way, what's happening…keep [his] thoughts into [his] hands and [his] motions." To help her stay engaged and retain information, Caitlin noted:

> "A lot of times, I space out when someone's talking to me…I think drawing and hand movements really helped me stay engaged. If, like, I can move my hands or picture it a little bit, I can commit a little bit more to memory and then be able to see it."

Discussion and Conclusion

All of our participants identified challenges related to mathematical learning, commonly associated with dyslexia – including reading text, writing and understanding symbols, and taking notes in class (MacCullagh et al., 2016; Perkin, 2004; Searle & Sivalingam, 2004). Together, our findings suggest that a larger obstacle to undergraduate mathematics for these students may be in place before any reasoning or calculation is undertaken: A barrier in translating mathematical text to mathematical meaning, structure, and action.

Mathematical texts possess features that can prove challenging for students to navigate, such as complex sentence structures, precise definitions, specialized terminology and symbols, and a high density of concepts (Shepherd et al., 2009). For students with dyslexia, these features may compound existing difficulties with processing information from text (Perkin & Croft, 2007). Mortimore and Crozier (2006, p. 240) found that USDs disproportionately struggled with "organizing essays" compared to their non-dyslexic peers, suggesting that dyslexia exacerbates the challenge of organizational or language-heavy exercises for these students. Our findings suggest that these organizational difficulties extend to processing and structuring mathematical information presented in text, and producing a linear, coherent narrative in the way of a solution to a problem. This complements the reported challenges of research mathematicians with dyslexia in “translating mathematical thinking into text” (Lambert & Harriss, 2022, p. 99), as well as those of one postgraduate engineering student with dyslexia, who encountered problems “structuring written work” and “deciding what to write” (Perkin, 2004, p. 7).

To combat their difficulties, many of our participants identified *writing* as a way of (visually) structuring their thoughts, giving them confidence and assurance in the information they had read. Students also used their hands to support problem-solving activities and to communicate their solutions, sometimes relying on their gestures to supplement key aspects of their answers. Reframing mathematics as a visual activity was standard across our participants, echoing Bacon and Handeley’s remark that “a preference for reasoning strategies based on visual processes may be a robust feature of the dyslexic cognitive profile” (Bacon & Handeley, 2014, p. 337). An inclination for ‘visual thinking’ has been anecdotally noted by a number of authors (e.g., Griffin & Pollak, 2009; Lambert & Harriss, 2022; Perkin & Croft, 2007; Trott, 2003a, 2003b) and is repeatedly among the guidance given for supporting USDs (Trott, 2003a, 2003b). We found our participants identified strongly with this characterization, and often that mathematical meaning-making was synonymous with ‘visualization’ in their accounts.

Participants’ accounts also indicated that the cognitive load in simultaneously remembering and manipulating task-relevant elements imposed a substantial challenge (cf. Sweller, 1988, 2010). Swanson and Siegel (2001) argue that specific learning differences – including dyslexia – reflect “deficits” in WM, related to the phonological loop and central executive of the Baddeley-Hitch model of WM (Baddeley, 2000; Baddeley & Hitch, 1974). Bacon and Handeley (2014, p. 341) refine this view, asserting that dyslexic students’ reasoning is “disproportionately” negatively affected when they are required to remember visual patterns – proposing that the tasks of remembering and manipulating information are “competing for the same visual cognitive resource” and that disadvantage arises only under conditions of high WM load. To compensate, our participants described strategies such as minimizing cognitive demands (via selective attention or offloading) and rehearsing information to preserve it in WM. *Gesture* also appeared throughout the participants’ recollections of undergraduate mathematics, serving as a means of visualization, communication, and offloading (Risko & Gilbert, 2016; Kokushkin, 2024). In the context of high school students, Hord and colleagues note visual representations (including gestures) “may provide scaffolds for students with learning disabilities related to difficulties with working memory...to facilitate concentration on processing, storing, and integrating information” (Hord et al., 2016, p. 190). Future work of the authors will focus on the role of gesture and embodiment in mathematics learning for USDs.

We caution against drawing broad conclusions on dyslexic undergraduate mathematics education, due to the small sample size of our study and its focus on personal experiences. We also do not claim these challenges and compensatory measures are unique to students with dyslexia, or any specific learning difference. Dyslexia, however, introduces its own layer of complexity, and thus may disproportionally disadvantage undergraduate students on certain tasks. We believe these experiences of USDs, reported in their own words, offer a unique, rich, and informative perspective on the strategies and challenges they face when engaging in undergraduate mathematics learning.

Acknowledgments

The first author was affiliated with California Polytechnic State University, San Luis Obispo, for the experimental design, and collection and analysis of data for this paper. He is grateful to the Department of Mathematics therein for their support and financial compensation for interview costs.

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