1. Introduction

Spatial reasoning—the capacity to mentally represent, manipulate, and transform spatial relationships—is foundational to learning in STEM disciplines, from geometry and engineering to physics and data visualization. Yet, learners vary significantly not only in spatial ability but also in the strategies they employ to solve spatial problems. Understanding these strategic differences is essential for designing effective educational interventions, adaptive technologies, and diagnostic tools.

Cognitive theorists such as David Lohman (1989) have long argued that individuals adopt qualitatively different approaches to spatial tasks. He distinguished between piecemeal strategies, which involve local, step-by-step processing, and heuristic strategies, which rely on rule-based shortcuts and global processing. These distinctions, though theoretically well-established, have traditionally been inferred from post-task performance or think-aloud protocols, limiting their temporal precision and scalability.

Eye-tracking technology provides a unique opportunity to directly observe cognitive strategies as they unfold in real time. Mary Hegarty and colleagues have demonstrated that visual attention patterns—such as fixation duration, saccade length, and scanpath regularity—serve as reliable indicators of strategy use in spatial tasks. Their work reveals that high-performing individuals tend to adopt structured, goal-directed gaze behavior (e.g., early fixations on critical areas, low entropy transitions), while others exhibit exploratory or verification-based patterns (e.g., high scanpath length, frequent AOI revisits).

Building on this foundation, researchers such as Jarodzka et al. (2010), Just & Carpenter (1993), and Nazareth et al. (2016) have further linked gaze metrics to expertise, task difficulty, and cognitive load. These studies collectively support the claim that eye movements are not just perceptual traces but windows into cognitive strategy—particularly in spatial reasoning contexts.

Despite this progress, most prior work has relied on hand-coded or theoretically driven classification of strategies. There remains a critical gap in the systematic, data-driven exploration of which eye-tracking metrics most robustly characterize specific cognitive strategies. The present study aims to address this gap by combining cognitive theory, visual attention analysis, and machine learning methods to uncover and classify spatial reasoning strategies based on empirical gaze behavior.

This approach promises not only to refine our understanding of spatial cognition but also to advance the development of adaptive learning systems that can respond in real time to a learner’s visual and cognitive strategy.