Navigating with Intent: Supporting Metacognitive Regulation in Digital Wayfinding Interfaces

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Introduction

Modern digital tools such as mobile navigation have become essential for helping users navigate complex and unfamiliar cities or new urban environments. Whether these applications are used for rerouting during delays or heavy traffic flow, using them effectively requires more than simply reading maps. Users must actively manage and engage with their cognitive processes to make informed spatial decisions. This self-directed cognitive overthinking, known as metacognitive regulation, involves setting goals, selecting strategies, monitoring progress, and adjusting behavior in real-time (Flavell, 1979; Nelson & Narens, 1990).

From an evolutionary perspective, such capabilities have long supported adaptive decision-making. Early humans relied on spatial memory and planning to locate resources, avoid threats, and return to familiar locations. These evolutionary pressures contributed to developing cognitive abilities that remain central to digital navigation today. Closely tied to metacognition is executive functioning, which includes working memory, attentional control, and mental flexibility (Miyake et al., 2000). These processes underpin successful digital wayfinding.

This paper examines how digital transit platforms, such as MBTA Go and MBTA.com, support or hinder metacognitive regulation. Grounded in cognitive psychology and human-computer interaction (HCI), this review identifies opportunities to enhance usability by scaffolding users' cognitive processes during navigation.

Literature Review

Metacognitive Regulation and Executive Function

Successfully navigating digital transit systems entails more than simply reading maps or identifying routes; it requires the deliberate coordination of cognitive processes, such as planning, self-monitoring, and adaptive problem-solving. These executive-level skills fall under the broader construct of metacognition, defined by Flavell (1979) as the capacity to reflect upon and regulate one’s thinking. Metacognitive engagement supports a range of essential functions, including the formulation of goals, the selection of effective strategies, the interpretation of feedback, and the evaluation of outcomes (Nelson & Narens, 1990; Schraw & Moshman, 1995). In digital navigation, such regulation enables users to respond flexibly to unexpected challenges and make informed decisions throughout the wayfinding process. Metacognitive processes operate on both a global and task-specific level, influencing decision-making, emotional regulation, and motivational control during problem-solving (Efklides, 2008).

In wayfinding, these processes may inhibit distractions from nearby signage, updating transfer plans based on delays, or maintaining route sequences in working memory.

In addition, Miyake et al. (2000) defined executive functioning as a cluster of interrelated cognitive mechanisms associated with working memory, attention flexibility, and inhibitory control.

These are the processes that facilitate a successful application of metacognitive strategies. For example, in the same scholarly article, Miyake et al. (2000) presented that working memory enables users to retain spatial goals, promotes cognitive flexibility, and facilitates routes for any unexpected adjustments, while attentional control aids them in focusing on relevant stimuli. The collaboration between these systems plays a crucial role in facilitating an effective navigation system, particularly in dynamic or unfamiliar digital environments.

Critically, digital tools that do not adequately support these metacognitive regulation functions risk overburdening users. Whether unintuitive interfaces or insufficient feedback mechanisms are employed, they can exhaust the user's cognitive resources, leading to a decline in cognitive performance and user confidence (Sweller, 1988; Winne & Hadwin, 1998). Consequently, effective digital wayfinding depends on interfaces that actively facilitate and reinforce metacognitive and executive processes through thoughtful and user-friendly design.

Wayfinding as a Cognitive Skill

Wayfinding is a cognitively demanding process that requires individuals to interpret environmental data and make ongoing spatial judgments. Passini (1984) noted that wayfinding is not merely about physical navigation—it is an information-processing challenge that hinges on synthesizing multiple cognitive inputs, such as visual cues, directional symbols, and comparative route analysis.

A key component of this process is the development of cognitive maps, which are mental representations of spatial relationships (Tolman, 1948). The hippocampus plays a crucial role in shaping these maps, facilitating allocentric (map-based) spatial reasoning and enabling individuals to visualize environments from an external perspective (O'Keefe & Nadel, 1978). Conversely, egocentric navigation—such as relying on landmarks or turn-by-turn directions—operates within an individual's immediate frame of reference (Lawton, 1994). Strategy selection is also shaped by environmental factors such as signage clarity, cognitive load, and spatial anxiety, all of which interact with prior navigational experience (Hund & Minarik, 2006). Effective wayfinding requires individuals not only to retrieve spatial information but to evaluate the appropriateness of their chosen strategy—a process directly tied to metacognitive monitoring (Kato & Takeuchi, 2003). Effective Wayfinders also demonstrate metacognitive flexibility (Veenman, 2006), seamlessly shifting between these strategies to maintain orientation in dynamic environments.

Metacognitive Strategy Development and Feedback Loops

Spatial knowledge evolves through distinct phases. Building on Siegel and White's (1975) framework, users typically develop spatial awareness in three progressive stages: first, by recognizing landmarks (discrete reference points); then, by connecting them through route pathways; and finally, by integrating these elements into comprehensive survey-level mental maps. Novices interacting with digital wayfinding systems generally follow this trajectory, beginning with landmark recognition before advancing to more sophisticated spatial representations.

Feedback loops facilitate this developmental process. It is a mechanism that allows users to evaluate their navigation strategies' effectiveness and make real-time adjustments. As Nelson and Narens (1990) conceptualized it, this involves a continuous interplay between cognitive monitoring (assessing one's understanding) and control (modifying behavior). Thoughtfully designed interface elements—such as breadcrumb trails, positional markers, and dynamic progress indicators—function as external cognitive aids that complement users' internal self-regulation. Feedback timing also matters; immediate feedback supports online corrections, while delayed feedback enhances reflective learning and schema restructuring (Shute, 2008). Interfaces that present cumulative progress, such as visual timelines or animated routes, reinforce this feedback loop by making invisible progress visible—a design affordance that reduces metacognitive blind spots. Beyond preventing disorientation, these features actively cultivate users' capacity for reflective learning and strategic adaptation during wayfinding tasks.

Cognitive Load and the Risks of Poor Design

Effective digital navigation systems must carefully manage two cognitive demands inherent to the navigation task and those created by interface design choices. Sweller's (1988) cognitive load theory establishes this distinction, separating intrinsic and extraneous loads, resulting from poor interface design and implementation. Existing research studies have also shown that minor design issues, such as unclear button placement, inconsistent iconography, or overly complex menu structures, can increase extraneous cognitive load, significantly compromising users' strategic planning and progress monitoring capabilities. Cognitive load is not distributed equally across users—individuals with lower spatial skills, language barriers, or executive functioning impairments may experience higher extraneous load from the same interface (Paas & van Merriënboer, 1994).

Additionally, uncertainty or poor feedback can elicit stress responses that further compromise working memory and executive control (Pekrun, 2006), amplifying the effects of extraneous load. The impact of insufficient feedback mechanisms presents another critical challenge in navigation design. Users often struggle to identify and correct navigation errors when interfaces fail to provide explicit route confirmation, error notification, or progress visualization. This phenomenon was empirically demonstrated in Darken and Sibert's (1996) study, which found that inadequate spatial cues reliably predicted both disorientation and task failure rates. Such evidence highlights the necessity of interfaces that display navigational information clearly and actively foster users' metacognitive engagement with the wayfinding process.

Scaffolding Metacognitive Regulation through Design

Designing for metacognitive regulation involves intentionally incorporating scaffolds that support these self-directed processes. The goal-setting stage includes clearly defining user goals (e.g., selecting “Outbound to Lowell”) and making task options prominent. For strategy selection, users should be able to choose how to search (e.g., via lists or maps), toggle filters, or adjust trip parameters as needed. Monitoring tools—such as dynamic travel timelines, error alerts, or “You are here” indicators—keep users oriented and reduce the need to remember every step. Finally, post-task tools, such as trip history or success messages, support reflection, reinforcing learning and schema-building for future navigation. Scaffolded interfaces reduce user error and enhance metacognitive development by fostering awareness of one’s decision-making process—a concept central to adaptive expertise (Hatano & Inagaki, 1986).

Designs must also consider universal usability principles, providing assistive tools (e.g., simplified modes, auditory prompts) that accommodate cognitive and perceptual diversity (Shneiderman, 2000). These design implications are significant when considering individual variability, such as working memory limits, spatial skill levels, or neurodiverse needs. A user unfamiliar with a subway system may benefit from different supports than a daily commuter, and users under time pressure or cognitive strain may rely more heavily on visible prompts and correction mechanisms. Effective design accounts for these conditions by embedding metacognitive scaffolds—clear affordances, strategy flexibility, and feedback loops—into every interaction layer.

Design Review: Metacognitive Regulation in Wayfinding Interfaces

Home Screen: Task Initiation and Goal Framing

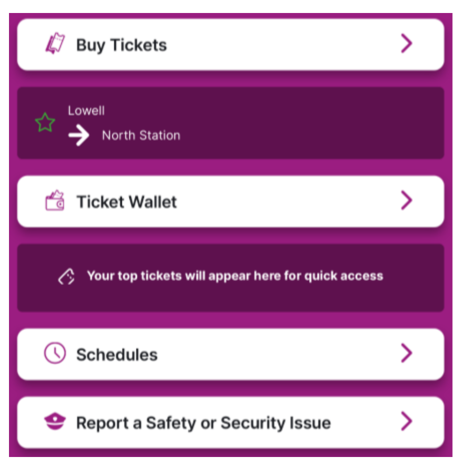

Figure 1: Homepage Entry Points for Goal Setting

The MBTA Go homepage (Figure 1) presents everyday actions such as “Buy Tickets” and “Schedules.” While these elements align with typical user goals, the visual hierarchy is underwhelming. Without bold text, large buttons, or prominent affordances, users, especially those unfamiliar with transit apps, may struggle to orient themselves and initiate tasks quickly. This undermines the goal-setting phase of metacognitive regulation (Zimmerman, 2002), where clarity and prominence are essential for framing action and reducing search latency. Redesigning the homepage to emphasize core actions visually would better support cognitive alignment from the outset.

Strategy Selection and Cognitive Flexibility

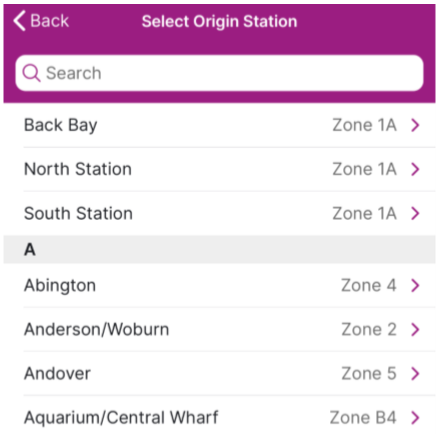

Figure 2: Route List and Search Strategy Interface

Figure 2 shows a searchable list of routes, offering scan-based and query-based selection strategies. This duality enables users to choose approaches aligned with their cognitive preferences—those with spatial memory may prefer to scroll alphabetically, while others may opt for direct searching. However, there is limited filtering, sorting, or categorization by travel time or destination. Veenman (2006) emphasizes that strategic flexibility is key to adaptive navigation. Without enhanced filtering options, users are left to mentally evaluate all options, which may increase cognitive load and hinder timely decision-making.

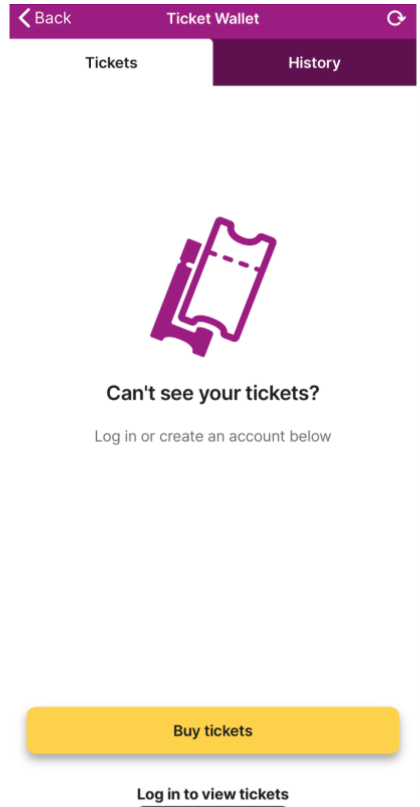

Figure 3: Ticket Confirmation

Breakdown in Error Awareness and Feedback

Figure 3 displays schedule data and a directional toggle (e.g., "To Lowell" or "From Lowell"). While this supports metacognitive monitoring—helping users verify the logic of their trip—it lacks visual indicators, such as progress bars, active trip highlights, or contextual labels. Monitoring progress is central to self-regulated performance (Winne & Hadwin, 1998). In the absence of dynamic feedback, users must mentally reconstruct their route logic, increasing reliance on working memory. Enhancing this view with real-time cues would reduce cognitive friction and promote confirmation of task alignment.

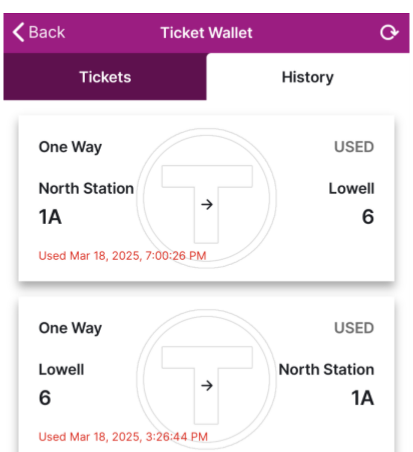

Figure 4: Post-Trip Reflection

Ticket History: Reflective Feedback and Cognitive Closure

The confirmation page in Figure 4 displays a timestamp and a "Used" label, indicating trip completion. This serves as a basic feedback loop, supporting reflection and outcome validation. According to Paris and Paris (2001), post-task reflection consolidates learning and contributes to the development of mental models. However, the interface could be enhanced with visual summaries, such as recent routes or completed badges, to reinforce schema-building more meaningfully. Without such cues, users may miss opportunities for learning through post-performance review.

Commuter Rail Website: Monitoring and Cognitive Updating

Clicking "Schedules" in the app redirects users to the MBTA.com website. This breaks mobile continuity and introduces a desktop-oriented layout into a mobile experience. In Figure 5, the list of train lines includes alert icons but lacks personalized routing or predictive suggestions. While the presence of an alert icon is helpful, its lack of context may leave users uncertain about the impact. As Montello (2005) and Darken & Sibert (1996) argue, effective wayfinding depends on just-in-time cues that assist recalibration. Without actionable feedback or alternative strategies, users are left to calculate disruptions and reroute independently, undermining mental metacognitive updating.

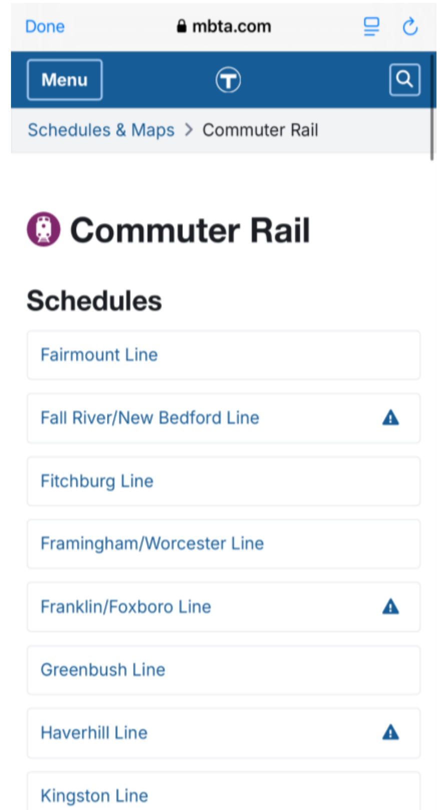

Figure 5: External Redirect to MBTA Website Schedule

Design Recommendations

Several key design enhancements based on the analysis of MBTA's mobile and web interfaces are proposed better to support metacognitive regulation and executive functioning during wayfinding.

First, the app should enhance initial goal framing by emphasizing core user objectives, such as purchasing tickets or viewing schedules. As shown in Figure 1, these elements currently lack visual emphasis. Using bolder icons, larger buttons, and more transparent labels would reduce search effort and promote faster task initiation (Zimmerman, 2002).

Second, the system should expand strategy selection tools, offering advanced filtering and sorting mechanisms alongside the existing route list and search bar. In Figure 2, users can search or scroll through routes, but additional options, such as filtering by zone or arrival time, would better support users with varied preferences and cognitive needs (Puerta Melguizo et al., 2012; Veenman, 2006).

Third, monitoring and directional feedback should be improved. Figure 3 currently displays directional toggles and static timetables but lacks dynamic route highlights and real-time updates. Adding active indicators, such as progress animations or current status markers, would strengthen self-monitoring and reduce cognitive uncertainty (Winne & Hadwin, 1998).

Fourth, the app could better support task reflection by building on the confirmation view shown in Figure 4. While the current interface includes minimal feedback, enhancements like color-coded history, “trip completed” badges, or shortcut access to recently used destinations would promote schema-building and reinforce metacognitive closure (Paris & Paris, 2001).

Finally, the system should eliminate cross-platform disruptions by avoiding the need to switch between the app and the MBTA.com site, as shown in Figure 5. Instead, a mobile-native schedule interface should integrate contextual alerts through iconography or messages, severity indicators, and predictive routing suggestions. This would reduce disorientation, support planning, and align with cognitive continuity principles (Montello, 2005; Winne & Hadwin, 1998).

Conclusion

This paper explored how metacognitive regulation and executive functioning underpin successful digital wayfinding and how the design of public transit tools supports—or undermines—these processes. Through an evaluation of the MBTA Go app and MBTA.com website, the review identified strengths and breakdowns in scaffolding cognitive processes such as goal setting, monitoring, and corrective feedback.

While certain features like directional labels and historical logs show promise, gaps remain in helping users recover from errors, reflect on tasks, or personalize strategies. To truly support diverse users navigating complex transit systems, interfaces must offer more than information—they must actively support thinking. By embedding metacognitive cues, dynamic feedback, and flexible task flows, designers can create tools that reduce cognitive load, enhance learning, and improve confidence in everyday urban mobility.

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