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Being Where? Putting Memory, Technology, and Wayfinding Together Again

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Abstract

Although wayfinding is a central domain for 4E research, much work on spatial cognition and navigation still operates within an internalist framework. This is particularly damaging in evaluating the cognitive impact of technologies like Global Positioning Systems (GPS), where negative assessments about 'de-skilling' and the digital disruption of biocognitive spatial memory capacities are widespread in science and popular culture alike. We offer a new, broader perspective for understanding the alleged technological fragmentation of spatial knowledge. Critically surveying evidence for GPS effects on spatial cognition, we reconstrue such effects as configurations of *wayfinding ecologies* – the flexible and dynamic distributed cognitive systems we use to navigate. Long before GPS, human spatial memory was far from complete or perfectly effective – more of a collage or a patchwork than a detailed map – and is heavily dependent on enculturation, shared social practices, and the specific features of experienced environments. Where there are negative effects of persistent GPS use on spatial cognition, these are not inevitable results of new digital systems acting out of the blue, but emerge from longer historical processes in which other forms of cognitive-technological coevolution configure the fragile balances of our wayfinding ecologies. What matters both psychologically and politically, we argue, is not simply *that* GPS technologies are used, but *how* they are used. There is still dramatic individual and group variability in spatial cognition and in the ways that navigation technologies are deployed in practice. Some users may become relatively passive in handing over all engagement with their environments to increasingly personalized algorithms. Others develop unique or expert strategies of skilful incorporation, adding new hybrid capacities to already specialized socio-cognitive practices. An analysis that resists nostalgia and techno-gloom can identify opportunities for deliberate ecological design to help shape conditions under which technologies operate, rather than accepting whatever configurations emerge from market forces or design defaults. There is no simple choice between resisting or embracing technological change, but a range of ways

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we can more or less thoughtfully and sensitively craft the wayfinding ecologies of our own shared future.

Keywords Wayfinding · Technology · Memory · GPS · Navigation · Cognitive ecology

1 Introduction

In the 21st century, transformative technologies have significantly altered how humans communicate, collaborate, and coordinate activities across space and time. Among these technologies and changes, the widespread adoption of satellite-mediated navigation stands out for both its speed and scale. In less than thirty years, these technologies have gone from being technical devices used by a limited number of specialists in the military, surveyors, hikers, and scientists, to a widely accessible and almost essential part of everyday life (Ceruzzi 2018). Today, billions of people routinely navigate complex environments with the assistance of digital maps and apps that pinpoint location, calculate optimal routes with turn-by-turn guidance, and provide contextual, personalised, and dynamic information about local surroundings and services.

Global positioning systems (GPS), digital maps, and location-based services have changed the way we determine where we are, where we've been, and how to get where we're going (Johnston et al. 2015). These shifts are generating considerable concern among both scientists and the public about potential cognitive consequences. Some worry that GPS use may be slowly eroding, disrupting, or fragmenting our spatial cognitive abilities, weakening our connections to the environment around us, and creating dangerous vulnerabilities when technology fails (Aporta and Higgs 2005; Hebblewhite & Gillett, 2020; Heft, 2013; Ingold 2000). Some of these concerns echo familiar anxieties that accompany any novel technology (Wartella and Jennings 2000; Orben 2020), but others may reflect genuine challenges posed by the unprecedented scale and speed of adoption. Are we experiencing a beneficial evolution of human-technology collaboration? Or are we undermining the development of core human functions?

To address these questions and better understand the dynamics of this technology-mediated problem space, we examine GPS effects on spatial cognition within their broader ecological contexts. We argue that these effects are best understood as *reconfigurations* of wayfinding ecologies - the distributed cognitive systems we use to navigate. Wayfinding ecologies encompass neural processes, bodily orientations, environmental features, cultural practices, and technologies that together enable the intentional and directed spatial movement needed for wayfinding. These systems are flexible and dynamic, as they adapt to different tasks, environments, conditions, and available tools. While digital wayfinding technologies like GPS devices and *Google Maps* enable remarkable capabilities and efficiencies that might free up cognitive resources and enhance other areas of human life (Brown and Laurier 2012; Clark 2025), they can also disrupt and displace older forms of navigation know-how (Aporta and Higgs 2005; Johnston et al. 2015). The implications and effects of such changes in wayfinding practice cascade across individual memory practices, social knowledge transmission, and broader cultural patterns.

Three questions guide our investigation. How do GPS technologies alter the ecological relationships between human memory, environmental engagement, and spatial learning? What new patterns of spatial knowledge and memory-technology coupling emerge from GPS-mediated navigation? And what are the broader implications of these changes for human spatial cognition, cultural practices, and the future of cognitive technologies?

Digital tools reconfigure the cognitive dynamics of human wayfinding ecologies by altering where and how spatial information is encoded, stored, and retrieved. This reconfiguration has several effects. For the *individual* it changes patterns of attention, perception, and memory. *Socially*, it changes how spatial knowledge gets communicated, stored and shared. And *culturally*, it changes how navigational expertise develops and transmits within and across generations. To explore these dynamics, we draw on theoretical perspectives from 4E cognition, distributed memory studies, and cognitive ecology, connecting these approaches with recent empirical research on spatial cognition and technology. In analysing these interconnected or nested changes across full and diverse cognitive ecosystems, we seek a more thoughtful view of our relations with new digital systems than much recent scientific and popular work that spreads what Clark calls "techno-gloom" (2025, p.1). While we also resist extremes of techno-optimism (the uncritical celebration of cognitive offloading), we are primarily concerned to complicate the kind of techno-pessimism that bemoans the loss of 'traditional' skills – what Rebecca Noone calls "the satnav lament" (Noone 2024, p.3). A focus on negative aspects of these technologies is prevalent in contemporary concerns about "cognitive deskilling", as if the new systems do not extend our cognitive capacities, but rather invade or replace them. The danger here, we argue, is that critics overlook the transformed operations of wider wayfinding ecologies, and pine for a lost past cognitive capacity that never was – overlooking the fact that human spatial knowledge has *always* been fragmentary (McNamara 2012) and socio-technically mediated and shaped (Hutchins 1995). As Feenberg (2000, p. 313) notes, "nostalgia is not a good guide to understanding technology". Instead, we analyse the complex redistribution of cognitive work across human-technology systems, and attend to both emerging capabilities and potential vulnerabilities. As Clark (2003, 2007) argues, once we recognize that the technologies through which we think may sometimes become part of us, we can carefully and critically reflect on the design of these technologies and whether they are facilitating or diminishing human flourishing.

We begin by establishing wayfinding as a paradigmatic example in 4E cognition and identifying key principles of a distributed approach to memory and wayfinding (Sect. 2). We then examine empirical evidence about GPS effects on spatial cognition, acknowledging findings that fuel concerns about undermined spatial learning and environmental engagement (Sect. 3). We contextualise these results by examining how GPS transforms modern urban wayfinding ecologies in ways that both amplify the fragmentation of spatial knowledge and the undermining of spatial memory, and exacerbate what we call an 'archipelago effect' (Sect. 4). Finally, we consider what the wayfinding ecologies perspective reveals about memory-technology relationships more broadly (Sect. 5), and conclude with implications for further research.

2 4E Cognition and Wayfinding Ecologies

Human spatial knowledge is not complete or perfect. Our knowledge of the environment is typically a "collage" or "patchwork" composed of regions of which we have subjectively detailed knowledge, surrounded by other regions we know much less well (Tversky 1993; McNamara 2012). Well before the advent of digital navigation systems, researchers demonstrated that our 'mental maps' of the relative locations of places at different geographical scales are often distorted, partial, and fragmentary, in diverse but systematic ways (Lynch 1960; Tversky 1992; Ishikawa and Montello 2006). This research drove reconceptualisation of what is meant by a "cognitive map", when it was realised that no-one's mental representations were metrically accurate, and were all subject to these systematic distortions (Holden and Newcombe 2012).

The particular ways that individuals navigate depend in part on enculturation and environmental experience. There is no 'natural' or universal bio-cognitive unfolding of a single suite of spatial capacities. When critics of new digital technologies lament the loss or disruption of our sense of direction, for example, or the GPS-driven fragmentation of spatial memory, we should ask what pure or untainted capacities are serving as the preferred and prior alternative. Moral panics about wayfinding technologies, we suggest, are sometimes driven by nostalgia for a kind of rich, complete, active, and exhaustive mental mapping that has rarely if ever been realized in practice. If cognition naturally incorporates diverse resources beyond skull and skin, it is not surprising that it is vulnerable to all sorts of changes in the external components of the cognitive ecosystems in question, and to manipulation of those external components by bad or deceptive actors (Spurrett et al. 2025).

2.1 Background and Foundations

Wayfinding has served as a paradigmatic case for understanding how cognitive processes extend beyond the boundaries of the brain. Our title echoes Andy Clark's groundbreaking book *Being There: putting brain, body, and world together again* (Clark 1997). We pitch 'Being Where?' as a question, to confirm that there are – still and always – uncertainties, choices, and open-ended options in our contemporary, digitally-mediated practices and theories of wayfinding. GPS technologies have neither solved nor ended the challenges of navigation and orientation in space and time, in everyday and scientific contexts alike (Liao and Brinner 2026, pp.1–2).

If spatial memory research in classical cognitive science focussed on internal computations, and if much mainstream cognitive neuroscience bracketed questions about how bodily, environmental, social, and technological resources participate in cognitive processes, 4E cognitive science, in contrast, recognises that these external resources can be constitutive components of cognitive systems, such that cognitive processes are embodied, embedded, extended, and enactive, or situated and distributed (Newen, De Bruin, & Gallagher 2018).

From the outset of 4E cognitive theorizing, wayfinding has been a central domain and case study. Clark and Chalmers' (1998) Otto remembers in spatial contexts that parallel the ways many people use digital navigation tools today. Otto, who has Alzheimer's disease, uses a notebook to help him navigate through New York

City. When the notebook is consistently available, automatically trusted, and easily accessed, it functions as part of Otto's cognitive system, with the external resource becoming a constitutive component of memory systems rather than a mere external aid. Hutchins' (1995) ethnographic study of naval navigation described how navigation emerges from a complex socio-technical distributed cognitive system. Navigation in this context is achieved through coordinated interaction between crew members, charts, instruments, social hierarchies, and procedures refined over time (Gillett 2022; Hutchins 2025).

Kirsh and Maglio's (1994) analysis of Tetris gameplay revealed how players use spatial rotations of game pieces to gather information about possible fits and configurations that would be difficult to determine through mental rotation alone. These "epistemic actions" manipulate the environment to reduce internal computational demands by making critical information more readily available to perceptual systems. In navigation contexts, epistemic actions include turning maps to align with current heading direction or using fingers to trace routes while planning journeys (Hutchins 2006). Environmental manipulations can transform cognitive tasks by making spatial relationships more perceptually accessible. As the classic case of the blind person's cane suggests (Merleau-Ponty 1945 [2012]; Bateson 1972), tools can become incorporated into spatial awareness in ways that alter the phenomenology of environmental experience itself, changing how spatial knowledge is acquired, maintained, and utilised.

Beyond these foundational cases, wayfinding has been a central domain across 4E theory. Cussins' account of 'cognitive trails' (1992) took navigating as a model for all forms of embodied cognition, while Haugeland (1995) argued that intelligent wayfinding capacities are distributed across the road to San Jose and the travellers following it. Sterelny (2010) used the example of street signs to support his idea of epistemic engineering. Gillett and Heersmink (2019) and Record and Miller (2018) examine extended epistemic virtues in relation to satellite-mediated wayfinding technologies. Haddington (2013) used a distributed cognition framework to conduct an ethnographic investigation of couples driving and navigating together. And Wheeler (2019) discusses "North Sense", a wearable technology that connects the user to the earth's magnetic field so that they can sense it. From these discussions we extract key principles for understanding wayfinding memory: (1) cognitive processes can extend beyond neural boundaries to incorporate technological and environmental resources; (2) navigational knowledge is often distributed across social and technological systems; (3) wayfinding involves embodied skills that transform how we perceive, experience, and engage with environments; and (4) different components of the cognitive system may complement each other rather than duplicating functions (Sutton 2010).

2.2 Cognitive-Technological Coevolution

These examples of distributed spatial cognition reflect broader patterns in human cognitive evolution. For Merlin Donald (1991), human cognitive development has been fundamentally shaped by the creation and use of external memory technologies that have characteristics qualitatively different from biological memory systems. While biological memory is flexible, contextual, and integrated with emotional and social experience, external symbol systems offer greater durability, precision, and shareability across individuals and time periods. Writing systems externalized linguistic memory, mathematical notation systems externalized quantitative reasoning, and cartographic traditions externalized spatial knowledge, each creating new cognitive ecologies that redistributed mental work between internal biological processes and external technological resources. Wayfinding, in turn, has *always* involved interconnected assemblages of technologies and practices in dynamic balance across changing ecologies.

Human spatial cognition is profoundly encultured; it is shaped by the languages and tools we use, the habits we learn, and the environments we inhabit (Henrich et al. 2023; Hutchins 1995; Levinson 2003; Turk et al. 2011). Performance in navigational tasks varies widely across populations, dependent on topography, level of urbanisation, and cultural prescriptions about how far children are allowed to roam from their homes (Henrich et al. 2023). Spatial cognition is also therefore highly variable and contextual, not uniform or universal.

Individual differences exist both in small-scale abilities like mental rotation and in larger-scale spatial capacities like sense of direction (Hegarty et al. 2006, 2023; Ishikawa, 2023; Ishikawa and Montello 2006). Notably, these abilities are also trainable and malleable (Nazareth et al. 2019; Uttal et al. 2013). Different environments, and the amount of epistemic engineering, afford and constrain different wayfinding systems too. Variations emerge from specific historical circumstances, geographies, and social norms rather than innate differences. Whether navigating Pacific waters by reading "seamarks" in wave patterns and cloud formations, or dense rainforest by tracking the sun's position, navigators develop effective strategies fitted to their environments (Davis 2009; Fernandez Velasco and Spiers 2024; Jang et al., 2019). The spatial competencies that any individual develops depend on the combinations of cultural context, technological tools, and environments they encounter. What we think of as 'natural' spatial abilities are always already products of culture.

The historical trajectory from prehistoric way-markers through cartographic traditions to contemporary GPS systems has been an ongoing process of cognitive-technological coevolution, what Hutchins (1995) calls "cognition distributed across time", where each innovation reorganises and redistributes spatial memory work between internal and external systems while creating new possibilities for human spatial activity. As Liebenberg (1990) notes, nature is *not* an open book, and learning how to interpret features of the natural environment presents significant challenges for safe and reliable wayfinding. Ancient way-markers externalized route knowledge and enabled travellers to follow paths established by others without requiring comprehensive environmental knowledge or independent route-finding abilities. Such paths and patterns create 'landscapes of movement' which serve as material cultural expressions (Snead et al. 2009). Maritime navigation traditions developed sophisticated external instruments (e.g., compass, sextant, chronometer) that enabled precise positioning and route planning across vast oceanic spaces that are immensely difficult to navigate through environmental observation alone. Each technological innovation created new cognitive ecologies with distinctive affordances and dependencies, along with new forms of expertise and vulnerability (Hutchins 1995, 2025).

Maps are a notable wayfinding technology. They drastically reshape how we see and think about the world and our place in it. Maps create and support novel forms of spatial reasoning by combining different scales of spatial cognition, from small-scale processing of objects visible from a single viewpoint, to large-scale environmental processing that requires movement and integration of multiple perspectives (Menary and Gillett 2022). Unlike direct environmental experience, which presents spatial information sequentially through movement, maps provide holistic representations of the environment – a ‘god’s eye’ view that enables apprehension of spatial relationships otherwise difficult to grasp (Menary and Gillett 2022; Uttal 2000). Learning to use maps transforms spatial reasoning capacities, with the map acting as a medium for conceptual blending of projection and environment (Hutchins 2005; Uttal 2000, 2005).

Importantly, this transformation occurs through active, embodied interactions, as when manipulating a map helps to identify and track routes and landmarks. These gestures enhance spatial reasoning and communication by providing visual information that supports recognition and understanding of spatial relationships (Newcombe et al. 2013). Through practice, people develop skills in integrating map symbols with environmental features in ways that could not be achieve by either direct environmental exploration or abstract representation alone. These differing ways in which people interact with their environment through wayfinding tools and practices also support differing spatial experiences (Ingold 2000).

Whether or not digital wayfinding is “the fulfilment of the geographer’s dream” (Aporta and Higgs 2005, p. 743), it is in different specific respects both continuous with and a qualitative departure from this coevolutionary trajectory. Like previous navigation technologies, GPS systems externalize cognitively demanding aspects of spatial processing, like path integration, route calculation across multiple variables, and real-time recalibration to changing conditions. However, digital systems differ in their relationship to human social dynamics and spatial cognition. The proliferation of GPS raises questions about how spatial cognition operates in our modern, technologically-mediated environments. We now survey recent research indicating that this integration may come at significant cognitive cost.

3 GPS Effects on Spatial Cognition

Two decades of research has suggested that GPS use can have significant negative impacts on spatial learning and environmental knowledge (Dahmani and Bohbot 2020; Gillett and Heersmink 2019; Miola et al. 2024). Such findings generate considerable concern about cognitive deskilling and technological dependency, and feed narratives about ‘death by GPS’ (e.g., Carr 2010, ; McKinney 2010; Milner 2016). We assess the scope and consistency of the effects in question, to provide solid grounding for our analysis of how GPS transforms broader wayfinding ecologies.

Empirical studies of the impact of GPS on spatial navigational abilities (including spatial perception and spatial memory) are conducted in a variety of conditions and contexts, using a variety of experimental measures and methods. Real-world studies, in which individuals move around an unfamiliar environment using either GPS or some other wayfinding technology, demonstrate undermined spatial learning in pedestrians (Ishikawa 2019; Ishikawa et al. 2008; Münzer et al. 2006; Sugimoto et al. 2021; Xu et al. 2022). Observational studies of people driving raise similar concerns about attentional patterns (Jensen et al. 2010; Leshed et al. 2008). More research has been done in virtual environments because of the challenges of real-world studies: it is difficult to get sufficient sample sizes, and real-world conditions often have larger sets of uncontrolled variables (Vigliocco et al. 2024). Comparisons of spatial navigation in real-world and virtual environments are carefully assessed and deployed by the scientific community (Ekstrom et al. 2018). In lab-based studies, walking and driving simulators show the same pattern: agents who use GPS in contrast to alternative wayfinding technologies have weaker spatial learning, performing worse on a range of measures (Burnett and Lee 2005; Cheng et al. 2022; Fenech et al. 2010; Gardony et al. 2013; Gramann et al. 2017; Löwen et al., 2019; Wunderlich et al. 2022; Wunderlich and Gramann 2018, 2021). The finding of undermined spatial learning has been found regardless of how spatial knowledge is measured, whether through sketch maps, landmark recognition tests, or direction estimation tasks (Cheng et al. 2022; Ishikawa et al. 2008; Wunderlich et al., 2021, 2022).

These consistent results across distinct methods and measures seem to support the suspicion that GPS use might be ‘bad’ for our brains and minds. But they do not settle the matter entirely, for a range of reasons. A first concern here, motivated by the distributed cognition framework, is that, as Clark puts it, ‘such consequences are intrinsically bad (representing real losses) *only* if you start off by identifying your mind and self with the capacities and activities of your bare biological brain’: if you are, instead, ‘a bio-technologically distributed self’, then ‘what such results display need not be shrinkage and loss so much as the careful husbanding of our own on-board cognitive capital’ (Clark 2025, p.3). This view contrasts with work on the ‘offloading’ of cognitive capacities that treats tools as only potentially *influences on* cognition, as entirely external artifacts acting on a prior internal core which is differentially cued by distinctive technologies, or as arrays of external stimuli that can at best temporarily substitute for or add to a pre-existing, stable mind inside.

Both reviewers challenge our line of thought here, in natural ways which it is helpful to address before proceeding. One suggests that “even if the extended mind thesis is true, one can still say that the empirical work on the cognitive costs of using GPS technology suggests that such technology is bad for the biological parts of our mind (i.e., the ability to internalize spatial learning), if not the extended technological parts”. The other wants us to insist on a prescriptive or normative point, that when and if certain spatial capacities “are not always available through the technology, [then] without developing these capacities individuals lose the ability to independently monitor and check the performance of the technology itself - a doom spiral of dependency”.

We disagree. If I (come to) rely on my calculator for doing long multiplication, that is not necessarily “bad for the biological parts” of my mind. If I (come to) rely on my therapist for assistance with emotion-regulation, that is not necessarily “bad for the biological parts” of my mind. The “biological parts” may indeed change, functionally and dynamically if not also structurally: but the further evaluative move, calling such change “bad”, is not always justified. Yes, as we argue below, certain transformations may be problematic, and our interdependence with external resources does mean that we are vulnerable to changes we can't control: but this is not because biological change is necessarily "bad". Likewise, preserving "natural" biocapacities is not in itself a virtue: in changing techno-cultural ecologies, what is "good" for us may precisely require the flexibility to reconfigure the interactive operations of "the biological parts of our mind".

Yet there are genuine vulnerabilities in the kinds of distributed cognitive ecosystems we are describing, and in certain circumstances disruption may indeed be real risks. In the few cases where studies have been conducted over periods of weeks, evidence still indicates that GPS undermines spatial learning. Minaei's (2014) large ethnographic survey of people in London compared those who relied heavily on GPS devices with those who did not. GPS users were worse at seeing London on a larger scale and could not draw a good map of the area. Ishikawa (2019) looked at how long and how often people use a GPS-style device – either for in-car or on-foot navigation: from never to more than 20 years; from never to everyday; and in what ways people use them (in unfamiliar places or for regular commutes, etc.). The survey was conducted in conjunction with a battery of spatial reasoning and navigation tasks, revealing a negative correlation between sense of direction and frequency and length of use of GPS. In contrast, people who used maps the most often had the best sense of direction and mental rotation abilities.

Research thus strongly suggests that GPS can undermine spatial learning and memory. The consistency of this finding indicates GPS use creates systematic changes in how spatial learning occurs during navigation. However, these negative effects are not inevitable consequences of all GPS use: further studies show that modifying the interface or the instructions provided by the GPS (like adding incidental landmark information to standard turn-by-turn instructions) can mitigate negative impacts on spatial learning (Krukar et al. 2020; Li et al. 2013; Liu et al. 2022a, b; Löwen et al., 2019; Gramann et al. 2017; Raubal and Winter 2002; Wunderlich et al. 2022; Wunderlich and Gramann 2018, 2021). Thus, the problem may not be with GPS technology per se but with how people use it.

There are several hypotheses on why and how use of GPS devices might sometimes cause the undermining of spatial learning. One possible mechanism involves altered attention patterns during navigation. Hejtmánek and colleagues (2018) used eye-tracking to show that GPS users spend significantly more time looking at devices and less time scanning environmental features during wayfinding. This attentional pattern has direct consequences for spatial learning and memory, because environmental features that receive less attention are less likely to be encoded for future use. This is one way that GPS use changes the cognitive work of navigation. It redirects attentional resources away from environmental observations and engagements and instead toward device or instruction monitoring. In contrast, other forms of wayfinding technology, such as a traditional map, require continuous coordination between one's location, the map itself, visible landmarks, and any existing relevant spatial memory (Gillett and Heersmink 2019; Ishikawa 2016; Li et al. 2013). In some forms of use, GPS technology can discourage this coordinative work by simply providing turn-by-turn instructions that require minimal spatial understanding. As such, users of GPS-style wayfinding technologies *may* be more passive if they do not engage in as much coordinative cognitive-motor work connecting the external representation and the environment around them, and do not build, maintain, update, and deploy a cognitive map or internal representational state tracking where they are. Instead, the device tells the user where they are on the display and gives them route directions which rotate with the person's direction and field of view. The agent does not need to work out their location or heading, or to plan a route – all the kinds of cognitive work that most wayfinding technologies prior to GPS required an agent to engage in actively. Other research confirms the impact of not being active in navigating and thus not encoding memories (Parush et al. 2007; McKinney 2010, ; Dahmani and Bohbot 2020).

Aporta and Higgs (2005), in ethnographic fieldwork on GPS use amongst the Inuit in Igloolik, noted such passivity arising from the way GPS can dislocate an individual from their surroundings, when they do not build a relationship to their local environment, to the places where they are, in order to tackle basic navigational tasks. Instead, basic navigational tasks are solved by the GPS device in a "black box" set of processes – ones which the user cannot see and need not comprehend in order to deploy them. This brings a radically altered experience of the spaces we move through. Drawing on Ingold's (2000) phenomenological approach, Aporta and Higgs (2005) describe this as "disengagement", a disconnection from environment that they identify as central to deskilling. Agents who do not have to engage in much effort to achieve a goal whilst using a tool, because the tool automates a lot of the work, can fall foul of "learned carelessness" (Parasuraman and Manzey 2010). When solving the navigational task is largely outsourced to the black boxed, automated processes of the device, agents can become complacent in accepting outputs without checking that they are accurate since the work very often is accurate. If the GPS does then occasionally give incorrect guidance, not only are agents less likely to spot this due to their passivity in the shared work, but they will also be less skilled in knowing how to tackle and repair the error.

These attentional shifts may connect to deeper changes in spatial reasoning. Ruginski and colleagues (2019) found that GPS use was associated with weakened spatial transformation abilities like mental rotation and perspective-taking skills which build integrated spatial understanding. These deficits may explain why some GPS users show poorer environmental learning. Without regular exercise of these spatial transformation abilities, that enable people to connect fragmented experiences into coherent knowledge – without regularly rotating maps to match heading, imagining views from different approaches, or updating position relative to landmarks – the capacities may gradually atrophy. Ruginski and colleagues (2019) found that this effect persisted even after controlling for existing navigation ability, suggesting that GPS creates its own pathway to diminished spatial cognition regardless of initial skill level (also see Ishikawa 2019).

But again, the fact that different people use GPS differently complicates the issue. Spatial skills vary substantially across individuals, and can also be refined and improved through training and practice (Ishikawa and Montello 2006; Uttal et al. 2013). Recent research reveals complexity in GPS effects by examining how people actually use the technology. Topete and colleagues (2024) investigated reported use of distinct GPS functions: turn-by-turn directions, route planning, time and traffic estimates, and finding specific services. These functions showed different relationships with spatial abilities. Reported use of turn-by-turn directions was most strongly correlated with poor self-reported sense of direction and higher spatial anxiety. In contrast, use of time and traffic estimates showed no significant correlations with sense of direction or spatial anxiety. Route planning and finding services showed intermediate associations. These functional distinctions suggest GPS technology is not uniformly problematic for spatial cognition, but that specific features engage differently with spatial memory systems. The study also revealed strategic alteration of GPS use based on expertise and environmental familiarity across different navigation scenarios. Users consistently reported less GPS use as environmental familiarity increased, regardless of their spatial ability levels. This pattern held across all GPS functions, and for individuals with both high and low spatial confidence. Additionally, people reported using GPS most frequently for time and traffic estimates rather than turn-by-turn navigation, suggesting they often use GPS to supplement rather than replace their own spatial knowledge.

There are also examples of strategic usage patterns which suggest that some GPS users develop skilful practices which maintain environmental engagement while gaining technological benefits. Professional navigators, like taxi drivers, provide compelling examples of strategic GPS integration. For example, Girardin and Blat's (2010) ethnographic study of Barcelona taxi drivers revealed sophisticated patterns of human-technology "co-evolution". Drivers developed "Satnav literacy" to manage the "spatial anxiety" that comes with navigating unfamiliar environments. This involved learning to assess geographic information quality, recognizing system limitations, and knowing when to trust or override technological guidance. This co-evolution created a "transformed ecosystem of artifacts" where GPS became one tool among many in professional practice. Drivers didn't abandon their accumulated spatial knowledge but instead developed hybrid competencies. They maintained and continued building an environmental understanding of the city while selectively using GPS for specific functions. The technology enhanced and complemented existing capabilities, with drivers reporting that GPS primarily served to reduce the cognitive load and stress of constantly calculating optimal routes in dynamic traffic conditions.

This example illustrates key aspects of wayfinding ecologies and shows that GPS effects depend on how the technology integrates with existing practices and skills. The same device that substitutes for spatial reasoning in 'dependent' users can become a selective enhancement tool for experts. These taxi drivers preserve their environmental engagement and spatial reasoning; they use GPS to augment rather than replace these capacities. This strategic use creates new forms of cognitive work, like meta-level decisions about information sources, quality assessment of technological guidance, and dynamic switching between navigation strategies. Thus, GPS use need not lead to spatial deskilling when certain conditions are met: existing spatial competence, cultural valuation of navigation expertise, and contexts that reward strategic rather than passive use.

Experts in using digital technologies perhaps have learned "how to both trust and question" the systems in question, having developed the "fluid meta-skills" which alert them to troubling or unusual features of specific wayfinding tasks or contexts, thus providing them with effectively resilient ways of remapping or rechunking parts of a cognitive ecosystem when unusual challenges arise (Clark 2025, pp. 2–3; Christensen et al. 2016). Such expert cognitive practices show how cognitive work can be redistributed and transformed rather than simply ‘offloaded’. This strategic use challenges a straightforward account of technological dependency and demonstrates that people develop dynamic relationships with navigation technologies based on situational demands and personal capabilities. If anxious, novice, or unfamiliar navigators do offload wayfinding capacities to digital alternatives, experts in contrast use the technologies in more sophisticated ways, to augment already rich skill bases and knowledge bases. These usage patterns indicate different modes of human-technology interaction in navigation contexts, which likely have different cognitive impacts. Rather than a straightforward account of cognitive decline, empirical evidence suggests a complex picture in which *how GPS is used may be more important than whether people use the technology at all*. This points toward the importance of understanding GPS effects as reconfigurations of wayfinding ecologies – of distributed cognitive systems - rather than simple technological dependencies, and sets the stage for examining how digital technologies transform the broader ecologies in which spatial cognition is developed and deployed.

4 Fragmented Spatial Cognition and the Archipelago Effect

This brief survey confirms that GPS is driving significant changes to human navigation and logistics, which correspondingly change the cognitive work needed for most wayfinding tasks. However, the extent of the changes varies across different cases of use, environmental contexts, and technological configurations – and importantly, GPS technologies have entered into ecosystems already shaped by prior sociotechnical changes. As we suggested in Sect. 1, human spatial capacities have always been fragmentary and patchwork. To understand GPS effects as ecological reconfigurations, this section examines aspects of the environments and infrastructures that already shaped spatial learning and memory before digital navigation arrived.

Modern cities often exceed the spatial scales that support comprehensive environmental knowledge through direct experience alone. Most urban residents know their neighbourhood intimately, their workplace district well, maybe a shopping area across town, and various other spots they frequent. But ask them about the neighbourhoods between these locations and their knowledge becomes vague or patchy. We term this intensification of the fragmentary aspects of environmental knowledge the “archipelago effect”, in reference to the way it creates isolated islands of familiar places connected by largely unknown transitional spaces.

The archipelago effect is partially due to how cities are built and the ways we move through them. Highways funnel traffic between destinations without requiring us to understand what we’re passing through. Public transport systems offset the need for personal knowledge of routes and places. Even the roads and footpaths make wayfinding decisions for us through their design. The built environment often channels movement in ways that reduce the need for spatial reasoning or complex decision making. This channelling reflects what Kirsh (1995) calls ‘the intelligent use of space’, in that pathways simplify the computational load required to navigate through the environment. Developed pathways support both perception and memory. Navigation infrastructures are cumulative forms of 'epistemic engineering' (Sterelny 2010) which allow for complex behaviours and decisions to be made more easily by altering the environment in ways which solve or support cognitive tasks. This matters because when GPS enters the picture, it is not necessarily bringing order to an unstructured setting, nor is it disrupting a pristine state of richly integrated objective spatial knowledge. It is, rather, operating within environments already designed to manage (and reduce) cognitive load through spatial organisation. The technology amplifies existing patterns rather than creating entirely new ones.

Fragmentation patterns are reinforced by the ways that we build transportation systems (Vertesi 2008). Subways, highways, and bus routes connect with stations and hubs that create what Augé (1995) called "non-places" – spaces designed purely for moving through rather than being in. As Lewicka (2011) notes, 'non-places' are characterised by transience, anonymity, and are 'devoid of character'. The homogenous, unremarkable nature of these spaces detracts from unique emotional experiences or attachments to them. The result is that people know how to access and move between destinations through transportation infrastructure, but remain experientially disconnected from the environments they traverse. This can create forms of spatial dependency where navigation competence relies entirely on maintained infrastructure systems, while the spaces themselves remain cognitively and emotionally inaccessible. GPS technologies operate within these broader ecological conditions, while introducing additional factors that may accelerate and intensify environmental disengagement, keying into the affective aspects of wayfinding which are constant accompaniments to or components of spatial cognition (Sutton 2024).

We can now connect the possible negative effects of cognitive disengagement surveyed above with these socio-cultural and historical developments. An intensified archipelago effect may emerge and become entrenched through two interacting processes, where GPS guides users along disconnected routes while simultaneously eroding the cognitive abilities needed to integrate those routes into unified spatial understanding. Complex urban environments serve as the settings and stimuli, and GPS use can actively deepen the disconnection by discouraging the cognitive work that builds both immediate spatial knowledge and enduring spatial reasoning capacities.

Traditional wayfinding ecologies in smaller-scale environments typically involve direct environmental exploration, social transmission of spatial knowledge, and navigation technologies (like maps) that require continuous environmental coordination. These configurations promote integrated spatial learning because successful navigation demands understanding of spatial relationships and environmental features. Modern urban wayfinding ecologies involve quite different configurations of these distributed components. Environmental layouts often exceed scales manageable through direct exploration alone (Waller and Nadel 2012), while transportation systems enable movement without environmental engagement (Appleyard 1970). Increasing urbanisation and mobility create competing pressures on spatial learning that can exacerbate the fragmentation of wayfinding knowledge. However, the burden of wayfinding in complex urban environments is mostly offset or augmented by epistemic engineering: the widespread availability of reliable maps, efficient transport networks, and standardised urban layouts have reduced the need for local spatial expertise.

The environment in which a person grows up has lasting effects on their spatial abilities. There is widespread evidence that spatial navigation abilities change across the lifespan (Bohbot et al. 2013; Ekstrom et al. 2018; van der Ham et al. 2020). Experiments show that younger people are much more likely to use landmark strategies – building survey knowledge of the environment based on relations between landmarks – while older people are more likely to use route strategies – remembering decision points on a memorised route (Bohbot et al. 2013; Iaria et al., 2003). The evidence shows a general decline in wayfinding performance with age, but notably this decline is differential, based on the kind of environment in which a person grew up and lives in. On average, an older person who grew up in a rural environment can retain comparable or better wayfinding abilities than someone ten years younger who grew up in an urban environment (Spiers et al. 2023).

Beyond this rural-urban distinction, the internal structure of cities also shapes spatial development. Evidence from Sea Hero Quest, an online game which collected navigation data from millions of people around the world, bears this out (Coutrot et al. 2022; Spiers et al. 2023). Spiers and colleagues used a measure of the amount of disorder in cities – which differentiates between the grid-like cities of North America and more chaotic cities like those found in Europe (Boeing 2019). They found that people from ‘chaotic’ cities were better at spatial navigation compared to people from grid-like cities. This suggests that environments which demand more spatial problem-solving cultivate stronger spatial abilities, while environments that simplify navigation reduce the need to develop and exercise those capacities. Well before GPS adoption and ‘dependence’, some urban environmental conditions were already shaping spatial cognition in ways that reduced flexible wayfinding competence. So, in some cases, GPS enters ecologies already configured to minimise spatial cognitive demands.

Cultural practices of spatial knowledge transmission also affect the formation and function of wayfinding ecologies (Aporta and Higgs 2005; Gillett 2018; Henrich et al. 2023; Hutchins 1995; Menary and Gillett 2022). Communities with strong traditions of environmental knowledge, shared know-how, and collaborative navigation may maintain more integrated spatial understanding, even within complex urban environments. The social dimensions of wayfinding ecologies interact with technological and environmental factors to shape spatial learning outcomes. GPS effects on spatial knowledge fragmentation should therefore be understood as interactions between technological affordances and broader ecological conditions. In contexts where environmental scale, transportation systems, and cultural practices already promote spatial fragmentation, GPS use may produce relatively modest additional effects. In contexts where older or other wayfinding ecologies support integrated spatial learning, GPS adoption may create more dramatic shifts toward archipelagic patterns.

This ecological perspective on spatial knowledge fragmentation has important implications for understanding both the challenges and the opportunities created by widespread GPS adoption. Rather than seeing the archipelago effect as technological disruption of “natural” spatial cognition, we might understand it as a biocultural development, in the context of ongoing tensions between mobility demands that require spatial competence and technological solutions that reduce the need for, or transform the nature of, such competence.

5 Wayfinding Ecologies: Implications and Extensions

We have argued that wayfinding is achieved through distributed ecological processes which cross brain-body-technology-environment systems. Rather than treating spatial memory as an internal cognitive capacity that GPS either enhances or impairs, the ecological approach reveals how epistemic engineering, and different combinations of technologies, social infrastructures, and environments create distinctive wayfinding configurations. Different wayfinding ecologies entail different forms of cognitive work, with varying affective and cognitive constraints and outcomes for navigators.

5.1 Implications for Cognitive-Technological Coevolution

Navigation is one of humanity's oldest cognitive challenges, one we share with all other motile organisms (Shettleworth 2010). The technological transformation of human navigation is instructive for understanding broader patterns of cognitive change. Historical precedents illustrate how technological transitions can restructure entire cognitive ecologies (Chrisomalis and Miton 2025). Tribble and Keene (2011), for example, identify the religious transformations of the English Reformation as, in large part, the deliberate rebuilding of cognitive ecologies to support new modes of learning and memory. Church spaces and processes were transformed in ways which created new "economies of attention" in reconfigured sacred spaces, with significant cognitive, emotional, and political effects.

Such cases show how epistemic engineering and cultural evolution inform and develop human cognitive capacities. Heyes (2018) argues that many distinctively human cognitive abilities are "cognitive gadgets" – not genetic endowments, but culturally evolved and transmitted skills. Like literacy or numeracy, wayfinding capacities are assembled through social learning within specific cultural niches. Technologies participate in this process by transforming both the problem space and the environments within which cognitive development occurs. Wayfinding ecologies are part of broader processes of cultural niche construction that alter how spatial abilities develop. As Hutchins (1995) notes, the fundamental question of orientation for humans is not "Where am I?", but "How can I use these wayfinding practices and tools to work out where I am?". The interconnected technologies and practices of a wayfinding ecology transform the epistemic structures through which spatial knowledge is acquired and transmitted across generations.

These culturally constructed niches shape cognitive development as powerfully as biological inheritance. Hutchins (1995) documents how the nautical wayfinding ecology was cumulatively constructed through refinement and expansion of technologies and practices for determining speed with chip logs, star charts, and sextants to estimate position at night; the magnetic compass altered orientation patterns which previously used the passage of the sun; the new chronometers allowed for accurate measurement of longitude (prior to this sailing at sea over long distances was incredibly challenging and dangerous). Central within this ecology was and is the sea chart: the result both of cumulative efforts of multiple generations to collectively map the world systematically, and of the creation and refinement of reliable measuring devices and mapping projections, ahead of today's easier-to-use maps (Johnston et al. 2015). This material culture is a cumulative way of storing, refining, and altering intellectual resources. The developmental trajectories of agents learning the practices by which to use these tools are thereby transformed (Gillett 2022). The invention of GPS devices is dependent on other wayfinding technologies, many of which it renders obsolete, in turn altering again the development of spatial skills.

GPS adoption also restructures 'economies of attention' in socio-cultural context. Aporta and Higgs (2005) documented this among Inuit communities in the Canadian Arctic. For generations, Inuit navigation had depended on intimate environmental knowledge transmitted through slow teaching and apprenticeship. Elders taught youth to read wind patterns in snow formations, recognise subtle variations in ice colour, and navigate by stars under different conditions. This knowledge system integrated practical wayfinding know-how with other cultural knowledge and survival skills. However, the introduction of several technologies significantly affected these traditional methods. When snowmobiles became available and widely used, the noise of the motors prevented the sharing of oral history and knowledge in the traditional way, and the speed of travel reduced the ability to attend to more subtle features of the landscapes. This pattern was then further amplified with the introduction of GPS. The adoption of GPS by younger generations has disrupted the transmission of this extended corpus of knowledge and know-how, as it allows young hunters to travel even faster. Technological threats to traditional knowledge emerged and grew quickly enough in these communities: but the effects of GPS were not isolated or disconnected from other changes in the broader ecologies.

Contemporary market dynamics do accelerate the sociocultural and cognitive changes engendered by satellite-mediated wayfinding in unprecedented ways. Zuboff (2018) labels these circumstances "surveillance capitalism", as tech companies extract personal data on which to train their behavioural algorithms. Geospatial information is a sought-after commodity because it can be used to accurately predict a person's future movements (Song et al. 2010), and to re-identify a person from anonymous data (de Montejoye et al., 2013, 2015). Furthermore, navigation apps and apps which utilise or combine with geospatial information are competing for ease of use and efficiency. In many cases, each iteration removes additional cognitive demands from users. Predictive routing eliminates route planning, real-time rerouting removes the need to track alternatives, and augmented reality overlays eliminate map interpretation. These features appeal to consumers and generate profits, and thus create economic incentives for ever-greater cognitive offloading.

Another consequence of the imperatives of capitalism in digital technologies is the phenomenon of "enshittification" (Doctorow 2023), whereby online platforms have degraded performance over time for their users whilst prioritising their business customers and profits. Indeed, some users report that *Google Maps* is becoming worse at providing wayfinding solutions (Grifski 2025). And if some agents are overly reliant on such digital products, their enshittification could have significant negative outcomes both affectively and cognitively. Doctorow argues that enshittified platforms systematically exploit their most dependent users – those with fewest alternatives, who are least able or likely to leave. Surveillance capitalism already enables platforms to identify patterns and target users accordingly (Zuboff 2019). One can imagine circumstances in which tech companies identify users most dependent on route suggestions, for instance, and algorithmically exploit that dependency through differential pricing, degraded service, or manipulative nudges towards paid advertisers and products. But this is not inevitable: alternatively, relative to Ishikawa's (2016) framework, digital wayfinding technologies could put the emphasis back on the agent to be more active in coordinating between brain, the tool, and the environment.

Emerging technologies suggest even more comprehensive transformations ahead. Autonomous vehicles may eliminate passenger awareness of routes entirely. Augmented reality could overlay navigation instructions directly onto visual perception (e.g., Liu et al. 2022a, b). Although awaiting broader empirical test, each innovation promises greater convenience while further reducing human engagement with the environment and the need to exercise spatial reasoning. But, as we've emphasised, this is not the only possible path into the future: in contrast, many artistic or activist interventions deploy the same technologies for different aesthetic or subversive ends, for example building counter-surveillance capacities, or supporting mutual tracking and on-the-fly decision-making among otherwise marginalized groups. For example, *Ushahidi* and *OpenStreetMaps* are non-government and non-corporate controlled crowdsourced cartographic enterprises (Bray 2014), which demonstrate that alternative configurations remain possible even as market pressures push in particular directions.

5.2 Cognitive Ecologies Beyond Navigation

This analysis of wayfinding reveals how memory operates through what might be recognised as 'nested coordination' across multiple timescales (Bietti and Sutton 2015). Nested coordination refers to how cognitive processes are informed across multiple interconnected and complementary timescales — immediate (moment-to-moment attention and action), developmental (learning and capacity formation over months and years), and cultural-historical (knowledge transmission across generations) — with changes at each scale influencing and constraining the others. In GPS navigation, altered attention patterns may accumulate into diminished spatial abilities over developmental time, which reshape cultural practices of spatial knowledge transmission. Each scale constrains and enables the others through feedback loops that relay and amplify initial technological effects.

Within wayfinding ecologies, environments and tools provide stability that maintains coherence across different navigational tasks and contexts. A familiar cityscape anchors spatial memory over periods of years (Jeffery et al. 2024), while maps offer consistent representational frameworks that support learning and recall (Hutchins 1995; Uttal 2000). However, changes to either component ripple through the entire ecology: urban redevelopment disrupts established cognitive maps just as switching from paper maps to GPS transforms how spatial information gets processed. These interdependencies mean that wayfinding ecologies must achieve coherence through the mutual stabilisation of their components across timescales, making them both resilient and vulnerable to technological or environmental disruption.

These dynamics extend beyond navigation to characterize memory-technology relationships in other domains. Smartphone notification patterns demonstrate similar nested effects. Immediate interruptions fragment attention through constant task-switching (Kushlev et al. 2016). These momentary disruptions accumulate developmentally into reduced capacity for sustained focus (Ward et al. 2017). Culturally, new norms about availability and response time emerge that further entrench fragmented attention patterns. The scales interact, with cultural expectations and habits encouraging notification checking, which reinforces attentional habits, which shapes developmental trajectories. Algorithmic content curation follows comparable patterns. Immediate convenience in finding information may reduce exploratory search capacities over time (Bhargava and Velasquez 2021), while cultural shifts in how knowledge communities share understanding create new forms of informational fragmentation. These reconfigurations are not only cognitive but social and political. New technological arrangements – redistributions of the heterogeneous resources of a cognitive ecology, and significant shifts in their interactive operations and balance – bring new vulnerabilities and new forms of power (Krueger 2023; Osler et al. 2024).

Along with a new norm of always being able to access information about one's location also come norms and expectations that others can always know where we are too. As Bray (2014) puts it "We may know exactly where we are at all times, but others know as well, whether we like it or not". Dobson and Fisher (2003) refer to this as "geoslavery": the label highlights that this situation often comes across as mandatory or inescapable. But, as Hebblewhite and Gillett (2020) stress, the route suggestions and geospatial information one can receive from a digital device are distinct from the "disclosure nudges" that these devices require users to reveal their locations to others (usually companies using the data as described above). Just as it is possible to design digital wayfinding technologies that mitigate undermined spatial learning (e.g., Gramann et al. 2017), it is also possible to design digital wayfinding technologies with location privacy preserving mechanisms (Jiang et al. 2020). Again, a pessimistic or romantic account is not useful since it too easily slides into a deterministic stance of futile acceptance (see Feenberg 2000). Instead, an ecological approach clarifies the ways in which cognitive and social aspects of these wayfinding technologies intersect, and highlights that variable configurations of technologies and practices are and have always been possible. This provides more fertile intellectual ground for critical discussions about which aspects of digital wayfinding technologies do undermine human wellbeing in its related cognitive, affective, social, and political forms. Work in environmental epistemology provides a complementary approach. Just as wayfinding ecologies can be configured in ways that support or undermine spatial learning, digital environments can be designed in ways that foster or hinder epistemically healthy dynamics and outcomes (Amico-Korby et al. 2024a, b; compare Rowlands 2005).

This consideration of wayfinding ecologies explains how memory-technology relationships reflect dynamic reconfigurations of cognitive work. GPS effects exist within these broader dynamics, as different assemblages redistribute attention, reasoning, and environmental engagement across brain-body-technology systems. These reconfigurations cascade across scales, from momentary attention patterns to developmental trajectories to cultural knowledge transmission practices. The wayfinding case provides a template for understanding how emerging technologies continue to reshape human cognitive practices in both beneficial and problematic ways.

6 Conclusion

GPS can undermine spatial learning and memory: the research so far is clear and consistent about this. These effects are fair causes for concern, particularly given the unprecedented scale and speed of GPS adoption. But placing these effects in proper ecological context changes how we understand both problems and possible responses. Human spatial cognition is known to be partial, distorted, and fragmented. Mental maps reflect systematic patterns of emphasis and omission rather than objective geographical accuracy. Individual differences in spatial abilities are substantial, as these abilities are highly malleable and culturally shaped. Technologies have always been involved in wayfinding, from prehistoric way-markers to maritime instruments to paper maps. Each innovation makes some cognitive challenges of wayfinding more manageable. A realistic picture of our spatial cognition *before* GPS suggests that the new digital systems do not suddenly disrupt or suppress previously rich and untainted biological capacities, but rather amplify – in variable ways – complex socio-technical alterations to prior ecosystems that were already in historical process.

GPS is a leap forward in wayfinding technologies and a qualitative departure from previous innovations. Unlike paper maps or other wayfinding instruments that still require environmental coordination and spatial reasoning, GPS can enable effective navigation with minimal engagement with surroundings or spatial thinking (Aporta and Higgs 2005). However, as we have noted throughout, whether GPS actually eliminates environmental engagement depends on patterns of use, interface design, and ecological context rather than being an inevitable consequence of the technology. What appears as GPS-induced impairment of natural cognitive abilities is better understood in developmental and ecological context (Noone 2024).

Cultural environments actively participate in wayfinding processes through both physical features (signs, landmarks, spatial organization) and social systems (local knowledge, community interactions, shared navigation practices). GPS enables people sometimes to navigate successfully while bypassing engagement with both these environmental and social dimensions. People can move through shared urban spaces without connecting to the physical cues or social fabric that traditionally supported navigation. The fragmented nature of spatial knowledge can be amplified by GPS – resulting in what we've termed the 'archipelago effect'. The fragmentation becomes social as well as spatial - GPS dependency creates isolated islands of individual movement that disconnect from the broader environmental and social systems through which wayfinding knowledge develops and circulates.

Human wayfinding is fundamentally social (Dalton et al. 2019). GPS potentially enables wayfinding ecologies where people move through environments as technologically supported but more socially isolated units, more able to disconnect from the environmental cues and social fabric that typically support navigation. The adage that 'no man is an island' captures the interconnectedness of human experience, as we rely on shared knowledge, social systems, and cultural environments to navigate both literally and metaphorically through the world. GPS can make navigators function as if they were islands within technological archipelagos, in a way, creating new forms of online-social-environmental coordination while losing the direct environmental and social embeddedness that has always characterised human wayfinding in situ.

We've emphasised that GPS effects depend on how the technology is integrated within broader wayfinding ecologies. The taxi drivers who maintain spatial expertise while gaining technological benefits, the interface modifications that preserve spatial learning by including landmark information, the strategic expert users who employ GPS selectively; these aren't exceptional cases, but demonstrations of how the same technology produces different outcomes when it integrates differently with existing skills, environmental contexts, and social practices. GPS effects emerge from these ecological integrations rather than being predetermined by the device itself. However, as noted, GPS devices and applications are also elements of industries which prioritise use, sales, and growth, among other nefarious objectives. Market pressures favour 'ease-of-use' interfaces and 'foolproof' processes, while surveillance capitalism tends to incentivise ever-greater involvement and integration with location tracking services and networks. This analysis and perspective points toward research tapping the distributed and collaborative nature of wayfinding in practice. Cognitive ethnography, following Hutchins' (1995, 2006) work on navigation teams, could examine how families, social groups, and professional communities actually coordinate navigation responsibilities and share spatial knowledge in GPS-rich environments (Haddington 2013). Such research might reveal how some groups maintain collaborative wayfinding skills and form hybrid systems, while others become individually dependent on technology. Similarly, studying the embodied and collaborative dimensions of navigation, and how people gesture, communicate, and coordinate movement through space, could help to reveal what gets lost or transformed when navigation becomes narrowed and individualised through GPS. These approaches would help identify specific social and embodied practices that support spatial competence in an increasingly fragmented world.

Some positive directions for deliberate ecological design are already clear from the research reviewed here. Interface modifications that include landmark information can encourage spatial learning while maintaining the navigational efficiency afforded by GPS devices (Gramann et al. 2017; Wunderlich and Gramann 2021). GPS instructions that reference visible features of the environment ('turn left at the church') rather than abstract directions and distances ('turn left ahead') keep users oriented to the surroundings. Navigation technologies could also support collaborative practices, for example, by enabling friends or communities to annotate shared routes with local knowledge. Urban design shapes these ecologies in turn. Cities with distinctive landmarks and legible spatial structure cultivate wayfinding capacities that generic 'non-places' and car-oriented environments do not.

As emerging technologies promise even more comprehensive transformations of human-environment relationships, from autonomous vehicles that eliminate passenger navigation entirely to AI systems that automate decision-making across multiple domains, understanding these ecological dynamics is pressing for protecting and preserving valued aspects of human cognition and culture while embracing benefits afforded by new technologies. The GPS case demonstrates that while technological effects are not fixed by the technology itself, patterns do appear reliably from how innovations integrate with existing ecological systems. This creates opportunities for deliberate ecological design to shape conditions under which technologies operate, rather than simply accepting whatever configurations emerge from either market forces or design defaults. The choice we face is not whether to embrace or resist technological change, but whether we can thoughtfully craft the ecological arrangements within which human cognitive capacities develop and establish technological systems that support human flourishing.

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