Exploring *Terra Incognita*: Wayfinding Devices for Games

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ABSTRACT
The ludic experience of exploring wilderness in gameworlds may be compromised by either the negative affects of disorientation or the conspicuous application of architectural principles known to support wayfinding. We use a novel device, inspired by insect navigation, to examine players’ situated acquisition of spatial knowledge to enable them return to the origin of their route while they explore an unfamiliar, synthetic natural world. We describe qualitative and quantitative data on player behaviour and distill themes to inform subsequent designs to assist players fulfillment when exploring settings and interpreting them spatially.

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1. INTRODUCTION
Experiences in natural places and simulations of natural places are more restorative than urban settings enabling people to retreat from life’s everyday constraints and psychophysiological stress [32]. Yet, while players may explore a game’s scenic wilderness their enjoyment may be compromised by the negative affects of disorientation and being lost. Designing to help people return to the origin of their route in unfamiliar terrain while they fluidly ‘discover it’ requires visual devices that facilitate both immersion and reliable wayfinding. Here, we explore the efficacy of a novel device to support people’s wayfinding in an unfamiliar, large-scale synthetic natural world. We first introduce the potential for gameworlds to support ludic exploration of landscape and suggest that imposing architectural principles derived from urban settings and external representations to support wayfinding compromises the immersive experience of wilderness. We propose that insect navigation may inspire designing to support the situated wayfinding inherent in exploring. Then we describe qualitative and quantitative data on players’ wayfinding behaviour in a naturalistic gameworld using a novel device to support parsimonious acquisition of spatial knowledge. We conclude by indicating insights to inform subsequent designs that will assist players’ fulfillment when exploring settings and learning about routes.

The photo-realism, richness and scale of 3D gameworlds offer players exploratory experiences. Sometimes such exploration is implicit to gameplay in worlds which cannot be rendered in entirety at one moment; for example, consider exploring the wilder-
earlier when they had a view of trees [35]. Natural places afford particular behaviours and engender a sense of fascination [16] and appreciation which seems to be cross-cultural and increasingly important to modern life (e.g. [17]). Drawing upon visual realism offers possibilities for designing psychologically beneficial experiences; for example a virtual Botanical Gardens stimulates long-term memory in Alzheimer’s sufferers as [12]. However, successful design of virtual wilderness relies on supporting the player as a “present explorer” as much as on aesthetics. While synthetic 3D wilderness is architectural [22] achieving a sense of unexplored terra incognita requires applying architectural principles with restraint. Architecture has long conceptualized experiential and spatial dimensions at different scales that guide wayfinding, environment memorability and imageability and support psychological engagement in built and gardened settings (e.g. [20, 32]). These have been integrated into design principles to support wayfinding for example, designing paths, landmark features and vistas to draw together distinguishable spaces (e.g. [36]). However, such engineering of virtual ‘natural’ places may undermine the aesthetic and exploratory experience of uncultivated wilderness.

Photo-real gameworlds rendered in classic linear perspective, (stretching the image as the plane of the space recedes at increasing angles of view) and seen in first person point-of-view (POV) support virtual modes of embodiment [23]. They simulate “bodily” interaction and engender presence in the terrain by putting a player in the avatar’s ‘shoes’. By harnessing the virtual body first person POVs interactions in gameworlds enable people to develop primary spatial knowledge similar to their experience in the physical world. Naturalistic experiences to immerse players should enable “thrown” interactions [e.g. 39] where a player responds fluidly and effectively to information embedded in the world. This depends on supporting situated “couplings” between landscape features and people’s perceptions and actions that temporally evolve activity in situ. Paradoxically, design principles applied to gameworlds often derive from evidence from recall of physical terrain [20, 9]. Since the types of landmarks described from memory in physical worlds and when creating routes in situ differ [21] applying theory on the saliency of landmarks recalled from familiar worlds may be inconsistent with situated exploring of unfamiliar spaces.

In the physical world people first encode landmarks using egocentric frames-of-reference which depend on their orientation during encounters and enable recognizing landmarks from the POV of their earlier exposure [15]. A frame-of-reference (FOR) is any coordinate system which instantiates objects and their orientation and is specified by its origin, orientation and relations between its axes. In narratives of spatial layout across small scales people tend to describe features using egocentric FORs and deictic references [30]; for example, “at the front of” is relative to the viewer. With more experience people encode object-centred, allocentric FORs which allows them to recognize landmarks from different POVs and, at increasing spatial scales, to interrelate objects [30]. However, encoding of allocentric FORs originates from egocentric FORs. Thus allocentric FORs depend on a person’s orientation during encounters [13] or require rotating and/or translating FOR to induce a POV to recognize a landmark from an unfamiliar orientation [3]. With substantial experience of larger spaces people form secondary spatial, or “survey”, knowledge [1] using extrinsic FOR to describe relations canonically (e.g. East) [30].

Many assistive devices to assist wayfinding in gameworlds use abstractions associated with secondary spatial knowledge that distract attention from the egocentric visualization. Orthographic plan projections in 2-D aerial maps and HUDs provide subsidiary wayfinding information on terra cognita but mappings between these representations and player’s situated spatial knowledge are prone to conflicts. For example, in unfamiliar physical terrain people have difficulties dynamically transposing their POVs or reporting their position using parallel projections [e.g. 5, 2]. Indeed, to reduce such interruptions to player’s flow many games instantly transport players to certain, named destinations (e.g. Silt Striders or Teleporters transport players in Morrowind from cities). This supports gameplay but does not enable players to build primary spatial knowledge. Further devices compensate for the absence of this knowledge; for instance players can use personal “recall” spells to instantly return to the last, often remote, location s/he marked with a “Beacon” spell.

We are interested in tactics to enable players to leverage “natural”, parsimonious strategies for acquiring and applying spatial knowledge compatible with situated exploring. Devices to support reflective exploration may assist immersive wayfinding and sense of place by helping players orient. People may be aware that they recognize landmarks based on experiences in which egocentric FORs are encoded. However they do not, usually, interact with the environment to deliberately prepare for future induction, for example by moving to learn about landmarks. We recently observed that displaying a visualisation of a participant’s past route on a digital map on a mobile, PDA-based, guide assisted orienting in the physical world [19]. We intended the past route visualization to help people to distinguish between areas they had and had not explored; however, it also appeared to assist orienting. Without past route visualization participants often paused when approaching a decision point to orient in order to align the map to their line of sight before proceeding. This corresponds with evidence that people with a good sense of direction do not normally use cardinal directions as reference points, but rather an anchoring direction embedded in the world which is relevant to their activities at the time, for example the direction in which they entered a forest [13]. We propose that designs that increase people’s experience of POVs of landmarks might mimic the way “turn back and look” behaviours help insects to find their way home [26]. Ants and bees use landmarks within navigatory repertoires when foraging but, unlike humans, in many circumstances these enable rapid learning by acknowledging that landmarks will not look the same on the way home as they do on the return. Insects have evolved specialised behaviour to acquire appropriate information about landmarks while traveling in one direction, which can be used to guide routes in other directions. For example, “by turning back and walking towards a landmark that it has just passed, an ant on its outward trip could, without much extra locomotion, acquire views to guide its return. Indeed, experiments on bees flying through tunnels suggest that local vectors for the homeward trip might be learnt on the outward trip” ([7] p. 723).

Here, we consider insights from an exploratory design to promote player’s acquisition of and reflection upon landscape information while traveling in one direction that is relevant to routes in other directions. The design enables players to record, visually, landmarks and vistas they encounter in an unfamiliar synthetic natural landscape from different POVs. In the physical world nature photography focuses a person’s attention upon environmental cues to support their orientation [13] and egocentric photo-based guides support moment-to-moment wayfinding (e.g. [4]). We distil insights to inform subsequent designs from detailed data on player’s situated exploratory trajectories in generating spatial knowledge.

2. METHOD

All data was collected using a gameworld which was custom-built by Redback Games, www.redbackgames.com, with Garage-
Games’ Torque engine. The environment, rendered in linear perspective, is a fictional outback landscape composed of a 4km² central area populated with geological features and fauna (Fig. 1) surrounded by an expansive, desolate desert containing only sand and hills. The colour palette and topology is consistent with north-east Queensland’s landscape. Wayfinding trials occurred in the populated area which would take 10 minutes to traverse at top speed were there no obstacles. Collision boxes prevent walking through hills, trees, large shrubs, and boulders but not through bushes, small shrubs, grasses, sand, mud, gravel or a billabong. There are only one species each of tree, bush, shrub and grass; however, there 10 different models of each tree and all features were hand-placed in a naturalistic way. Repeating patterns were discernable only for sand and water textures. Individual grasses become visible from about 3m. The sun is not visible in the gameworld and faint shadow effects do not indicate the sun’s position. The changing formations and drift of the clouds give no consistent indication of a player’s relative location.

We applied architectural principles to the world sparingly. There are two short canyons offering distinctive locational centres that are connected by the dry creek-bed to form a composite spatial structure. This natural path affords subtle continuity to support a player’s sense of direction between areas of the world they have been to, a centre or anchored location, to areas as yet unexplored. Long and short views from different points within the gameworld, terminate with various rocky hills to strengthen the experience of progression and continuity (e.g. [32]) with an understated series of revelations; for example trees cluster around the dry creek bed. The terrain is a mosaic of various grasses sand, mud and gravel occupying different shapes and size of ground cover and transitions between these provide “edges” [20] to assist distinguishing here from there (e.g. [36]).

We use 6 instances of the gameworld in wayfinding trials. The only differences between them are: the sky, representing different weather conditions and time of day; the players’ location at the start (initial spawn); and, the location of a unique, landmark marking the destination. This landmark, referred to during wayfinding trials as “the rune stone”, is a 3M tall, grey obelisk with an inscription (Fig. 1c). The distance between any start point and the rune stone varied from 100 to 900m, accounting for wayfinding of unfamiliar terrain at various scales, and it is not possible to see the rune stone from any start location. Players traverse the world by moving their avatar using standard for PC games keys (W: forward; S: backward; A: translate left; and D: translate right) and can combine keys to traverse obliquely (e.g. strafing). The camera is tethered to the avatar’s “eyes” and players see the environment in a first-person POV from a height comparable with human body size in the physical world. The geometric field of view [8] is approximately 60° horizontally and players can rotate the camera, 360° horizontally. While, players can rotate the camera 180° vertically, they cannot see their avatar’s body and visible footprints persist for only about 1 second before fading.

2.1 Interface, Compass & Photo-Device

We conducted wayfinding trials using two interfaces to the environment. The difference between the interfaces is the presence or absence of an assistive device enabling players to take virtual photos to record features for wayfinding or other reasons. The photo “album” appears at the base of the play screen with photos of about 25% of the usual view of the terrain. Only one photo is visible at a time and players can, at any time during their excursions, choose to view or hide the album and flick through the photos taken during that trial in order using the forward and backward arrow keys. In both interfaces a clock showing hours and minutes is visible in the frame around the game enabling players to observe their time in moving through the terrain (Fig. 1b). In the prototype discussed here there is also a “compass” in the top right hand side, which was added on the basis of a suggestion of player using the first iteration. This player found judging the camera’s horizontal rotation difficult and suggested that visual feedback from a compass would help players control the camera. The compass orientation at the start varied for each trial but was depicted as absolute across the trials.

2.2 Wayfinding Trials

We collected wayfinding data in the environment from four staff and five students in the school of IT. No participant had any prior experience of the gameworld. Three participants tested the first iteration of the interface to the prototype and based on that data we implemented changes to the interface without changing the environment. The first set of three participants (1 male and 2 females) were older and played fewer hours of games (mean age: 38, mean play: 1 hr/week) than the six males (mean age: 25, mean play: 16 hrs/week) who used the second iteration we described here. The players in the trials described here had a mean of 17 years computer use and 13 years playing games. Many of them had considerable experience in exploring RPGs.

All wayfinding trials were conducted by one researcher (author 1) and one player at a time. Players interacted with the game, running on a Mac laptop (chipset: ATY RV360MII) and front-projected onto a screen 1.5M vertically and 2.3M horizontally, using a wireless mouse and the keypad. While viewing. Players sat at table at 1.5M from the screen such that the display field of view subtended approximately 70°, which supports immersion and performance in navigation tasks [8]. Before the set of experimental trials we explained, in writing and verbally, the wayfinding tasks and demonstrated the start-up screen and a non-interactive view of the rune stone. We made it clear that players should move their avatar from the start location through the environment to find the rune stone which was always within 3 minutes if the player were to walk directly to it.

![Figure 1 Players used the interface without the photo device (a) and with the photo device (b) to wayfind to the rune stone (c) through different types of terrain which contains canyons (d) (e) connected by a dry creek bed (f) and rocky hills (g) trees, bushes (h), boulders and logs (j)]
We “escorted” all players in a training trial, to familiarise them with the interface and protocol, without exposing them to much of the terrain. We verbally guided all players along the same route from the start location to the rune stone in a small area of the gameworld. We asked players to climb a hill and pointed out the difference between the desert and vegetated areas and that the rune stone would not be in the desert. All players practiced using the mouse to rotate and pivot the camera and keys to traverse the terrain and take and view photos. When players reached the rune they pressed ‘F’ (labeled on the interface: “Objective found”), then when they believed they had returned to the start location, for that trial, they pressed ‘B’ (labeled “Back at starting location). The menu screen was displayed to indicate the trial was complete regardless of the accuracy in reaching the start.

We conducted five unescorted wayfinding trials per player; in each the start and the destination locations differed. Players had three goals: travel to the rune stone; return to the start location for that trial; and, notice any features in the terrain that may contribute to ‘survival’ (e.g. water, warmth, food etc.). If the player had not found the destination within 20 minutes we asked them to stop and return to the start location. We used three protocols for the 5 unescorted wayfinding trials differing only in the use of an assistive device. Players could use paper and pencil at any time in one trial, the photo device in two trials, and, neither paper or photo device in two other trials. We ordered trials to enable comparing similar distances in assisted and unassisted protocols, to minimise repeated exposure to regions in the gameworld and to account for order effects (e.g. learning about the world or using the interface).

2.3 Data Collection & Analysis
For all trial sets we recorded direct observations of and automatically tracked the players’ movements in the game world. We asked players to “think-aloud” by verbalising their actions and perceptions as they undertook trials provided it did not interrupt their flow or engagement in the game. In a short debrief after every trial we asked players to estimate their certainty of returning to the start location on a scale from 0, ‘completely certain that was not where I started’, to 100, ‘completely certain I am where I started’. We recorded player’s descriptions, sketches and maps of location of features of the environment that could contribute to their survival in the terrain verbally. We collected data on demographics, experience with synthetic environments and games, and reflections on the trials using a written questionnaire. Automatically logged avatar and camera movements and use of the photo device was exported into aerial map of the environment, a custom program and Excel for data analysis. We transcribed all comments and open and axially coded qualitative and quantitative data.

3. RESULTS
Players varied in the time to complete all the trials between 50 minutes to 2.5 hours. Depending upon the trial players spent a mean of between 6 minutes and 27 minutes from the start to the rune and then back to the start. Players found the rune stone in 87% of trials and, while several players mentioned that they “get lost easily in games”, they returned to within 10M of the start in 37% and within 20M in 75% of all trials. Players tended to be closer to their start location and more certain that they had returned to the start location when they used the photo device (Fig 2b). Generally, players tended to be fairly certain that they were within 10M; with a mean certainty across all trials of 77 (st. dev: 23) on the scale from 0 to 100. Players’ certainty tended to increase the longer that they spent looking for the rune but did not seem to relate to the time it took them to return from the rune to the start location. Players tended to take longer to reach the desti-

nation and return to the location where they believed they started when they used an assistive device (Fig 2a). One player was particularly poor at estimating their proximity to the start location being over confident 3 times and under confident twice and another’s certainty estimates was more often over confident. Three players mentioned that felt certain they were lost during their return journeys (e.g. “lost beyond any recognition”) or became uncertain of a recent direction taken (e.g. “wrong direction, I think”). One did not feel lost until they had a followed a route with some confidence before deciding that “this maybe a matter of perspective but I don’t think I’m right”. Others simply admitted they were “running around almost randomly … looking for a landmark that is familiar”. Players tended to refer to features to indicate their “lostness” for example, “looks a heck of a lot more desert than I would like” when using the paper device or “that’s not the same mountain” when comparing it to the photo.

3.1 Enjoyment & Embodiment
Several players mentioned they thought the world was attractive (e.g. “its pretty”) and the experiment was enjoyable (e.g. “It was fun”) or helped them gain further insight into methods of wayfinding they used in games. Sometimes comments revealed difficulties or frustrations; for example, “I could try cheating, see if F11 works”. One player said that the “landscape was too similar [and] started becoming tedious”, probably because they spent much time in the desert. Three players mentioned specific problems including depth perception, for example the “runestone looks closer than it actually is”, and spatial resolution, for example some players glanced at the laptop screen “to get a closer look because of [better] resolution”. Another player said he felt small: “I am used to being higher relative to horizon … the camera is pitched towards the ground”. All players felt the gameworld was large or they had, for instance, “no real concept of the size or scale” even after several trials. One player suggested a lack of familiarity with interacting with a game across their visual field, saying that their “eyes get sore from scanning all the screen”.

There were several indications that players draw upon virtual modes of embodiment [23] and compared their experience to the physical world. Players usually moved forward, rather than sideways translating, traversing obliquely (i.e. strafing) or moving backwards. Some mentioned embodied movement issues, such as it “Feels like I’m walking sideways”. We observed one player tilting his own body “to see around” a tree and gesturing with his thumb behind his head to indicate “behind me somewhere”. Another player remarked that not being able to swim in the billabong was “a bit suss”. Some players avoided taking routes, which required adjusting the camera; for example, rather than follow the narrow, rocky path within the canyon players tended to walk along the smoother surface of its walls. Players also seemed to recall places where they bumped into the collision boxes around trees or small rocks and tended to avoid them. Players’ beliefs about the behaviour of three eagles, which circle continuously over a confined area, further exemplify their sense of realism. Three players remarked upon the eagles yet none realized that they could act as a locational cue. One player after several excursions “noticed for the first time there was birds … I haven’t seen any before” when looking at an earlier photo in which eagles appeared at the same time as eagles flew into view in the gameworld. However, even this player believed their behaviour would mimic real eagles.

3.2 Landmarks & Frames of Reference
From a POv at ground level players primarily relied upon the different rocky hills as landmarks. Five mentioned hills and some
Figure 2 Players’ time in going to and returning to the rune per distance traveled (a); error and certainty in returning to their start location (b); variability in camera orientation prior to moving from the start location (c); and orientation of photos taken with the photo device (d). Examples of trajectories to the rune and return (f, g, h, i) on the same scale as the area marked on aerial view of the populated part of the terrain (e).

extremely frequently (e.g. one player remarked on hills 8 times in a trial). Players distinguished the hills by size and/or location relative to other landmarks (e.g. “big hill, right at the end of a big rift, or a river” and “grass on the top of the rock” or “rock with a tree”). Players tried to use hills to anchor start locations or along routes; two explicitly said they were “using this rock as an anchor point” or “I can remember that rock ... that’s my reference at the moment”. Others mentioned hills as waypoints, for instance “go to the left of that [hill]” or recalled hills at start locations, for example “just remembered that mountain was not the mountain of my starting point”. Players preferred some hills as landmarks saying “where’s my favourite mountain” or “small mountains don’t help” and some of their memories of a hill’s appearance were inexact (e.g. “that [hill] looks familiar I wonder if it’s the same one”). They sought distinguishing features such as: “that rock with those things to the right is where I started before”, “[that] square mountain is distinct” and “memorable u-shape mountain”. Only one player showed actively gaining allocentric knowledge: “heading round other side of mountain range to get another view”.

Players valued features as landmarks when they were visually unique and this often coincided with semantic uniqueness for their ‘survival’ goals. While four players mentioned trees at the start point they tended to ignore them as landmarks; for instance “I don’t see anything that’s going to help me see the way to get back ... there’s just odd trees and mountains” or expressed uncertainty about whether the “trees are all the same”. One player paid attention to trees variously mentioning the trees’ size density, or relative location (e.g. “big tree”, “I’m looking for lots of trees”, “the trees I am looking for were not near the river”). He then decided that trees “are all too similar ... but the mountains aren’t” in line with other players who said “trees are hard to distinguish”. This contrasted with logs which were rare, noted for survival by four players (fire or shelter), and valued as landmarks by all players. One said “I like that log, I can use it as a landmark, something I can come back to” and three mentioned looking for a log at the start location. All players encountered one or both canyons and noted their “Sheer ruggedness”, that they “would make a great place for a shelter” or “could indicate that there is water around”.

Players sought proximal cues, for example “I think I won’t be able to find it [starting position] because there was nothing noticeable near by” which are considered most effective to route guidance [26]. Players used the logs as proximal landmarks, for instance as one player said he was “going round [in a big circle] keeping the dead wood nearby”. Three players used the billabong as a waypoint, for example “water is close to starting location”, and one player drew the water in their sketch map. However, other proximal landmarks such as the dry creek-bed, different terrains and bushes bearing bright red fruit were less obvious. Three players mentioned the creek-bed as a landmark (e.g. “there’s that depression”) in relation to other landmarks or as a waypoint. However, none used it as path, as one said “that creek: that would be great to follow as a landmark but you can’t see outside of it”. Only two players mentioned seeing their berries; twice in the context of survival, “berries I can eat them”, and once in finding the start location “berries on these trees which could indicate where I started”. One player commented on the terrain at the start, a “clearing without grass” and “and recalled the “grass I walked through” at the end. Three players remembered the terrain at the start “was grassy” and noticed differences when comparing their photos to the terrain at the end, for example “grass is different, everything’s different, nothing [is] the same”. Two players mentioned the “arid area” or “looks like I’m heading into desert type areas”. With experience one started to “pay more attention to the floor instead of just mountains and trees; for example, I noticed a step between grass and desert”. However, generally, most of the features intended to be proximal landmarks, paths and edges [36] were not verbalised as good landmarks, for instance “just grass at starting point so nothing to show you exactly where you were”.

Some players commented on sequences of landmarks suggesting they constructed route knowledge. For example, one noted several waypoints “past those rocks on the left ... sides ... in between trees and rock and over dried up creek bed”. Some attempted to return along their outward route to the rune stone, for example “I’m trying to retrace my steps around ... should have been that rugged valley”; however, they found this difficult and often became unsure, for instance: “I’m trying to take a path to where I think I was but its impossible to tell if I am right”. Some combined their route knowledge with cardinal directions; such as, “My best chance to find my way back is to find the dead wood and then the water after that, depending on what was the red and white compass point”.

Players verbalised egocentric and extrinsic rather than allocentric FORs. All players articulated egocentric FORs at some point, such as, “mountain to my right and left and a big one behind me”. They realized there were no visible indices to absolute orientation
within the gameworld for example, after 5 trials and extensive distance, one said “there’s a shadow of some description, [but] I can’t see what its caste from”. While, the compass was unlabelled four players used cardinal directions. They coupled cardinal directions with landmarks, for instance saying “wood to the west: water to the north; mountain to north (close) south (far)” in reference to the start location or their initial trajectory: “let’s head of just north of west”. Three players demonstrated maintaining a general sense of their relative position in recognizing their start location using cardinal directions, for instance one said “[I] found wood which is probably due of west of where I started”, while another “dead trees for fire … water … approximately north-east-of where I started” and another “I’m heading due north, have to head due south to go home”. Four players linked cardinal directions to landmarks in using the assistive devices; for example, one sketched landmarks while saying “Go straight north”.

Two players mentioned using the compass strategically, one vaguely and one said they did not use it at all. Players sometimes used the compass in choosing their initial heading, such as “let’s go east” or “I’m just having a look around the compass to see if I can see the blasted thing without moving”. Only one player consistently guided their outward trajectory using the compass strategically (Figs. 2f & h). He explained: “do not stop or change direction unless you know what landmark you are next to”. Sometimes this worked for example “let’s go in a square” in one trial (Figs. 2f) and “I should come back to my starting point roughly north west”. At other times it did not work, for example: “[I] have gone in a big circle, its behind me somewhere” or “I think I’ve turned one direction the wrong way, which basically means I’m lost; but I’ll work it out … I actually shouldn’t be far from where I started”. He became progressively more attentive to the compass across trials; for example “I’m trying to be really picky, if I’m a couple of degrees off things go really skew”. Using the compass strategically tended to increase players’ accuracy and certainty in returning to the start location. However, generally players were not strategic, for instance “when I was walking I kept looking at compass every now and then to see which direction I was in” or abandoned a compass-driven strategy after starting out, for instance “I used the compass as a vague orientation at first” (Fig. 21). Players noted annoyance with the compass, such as if “arbitrarily points north” or “not the direction I’m facing” and that “it made me draw my map backwards”. Another felt that “what looks like a small change is a large change in direction”.

3.3 Scanning & Exploring

All players did not move the camera or their avatar for at least 5s (mean 40s) when they used an assistive device. When they used pen and paper no player moved the camera or avatar for at least 10s. All players in all conditions and all trials spent at least 6s scanning by moving the camera prior to moving their avatar. As one said “I always take in where I am … look around”. Players tended to spend the most time scanning prior to moving when they used the photo device due to the time incurred by taking photo. However, the amount of movement of the camera tended to be considerably less than the amount of movement of the camera without any assistive device and player’s individual camera movement was least variable when using the photo device. That is, they tended to rotate the camera more systematically when using an assistive device. There was an order effect with players tending to adjust the time spent scanning depending upon their success in finding the rune and/or returning to their start locations in previous trials. Players tended to scan more in the 180° ahead of them than rotating 180° behind, and often indicated that they “can’t remember what was behind”. Once they commenced mov-

ing players tended to maintain the camera ahead while moving and pausing to scan. Only one continuously moved the camera, saying “I’m into running … [I] keep moving the screen so I don’t zone off thinking about something else” and in this trial did better at finding the game objects than the start location. One player climbed a hill to “see what I can see” and looked back to starting place; however, for this unassisted trial it did not help his return to the start point or increase his certainty. Indeed, there was a slight tendency for players to be further from their start location when they had looked in the direction opposite to their first movement trajectory. One player repeatedly circled in the terrain occasionally realizing, “what I think I did was to go in an arbitrary circle to get back to where I started”, but also saying “it didn’t feel like a circle” (Fig 21).

Assistive devices encouraged players to turn back and look and record this information. All players drew symbols or sketches of hills at their starting point. For example, one said “I’m going to map where I go, draw landmarks from my starting point” and drew a distinctive hill, also saying “hopefully I’ll know what that means”. Another drew a map from atop of hill. Comments indicated when players were drawing they linked the hills to cardinal directions; for instance “three mountain ranges, east, north, west” and updated their sketches as they moved during excursions, for example adding to the map one said “I came from over there [on hill]” and drew that hill. Some players consulted their paper notes and sketches frequently, for example one looked at his map even when he had found the rune very quickly and another said “I am trying to look for a big mountain in the distance”. Some commented that their notes were unclear, for example: “That ain’t right … I should have been more careful, caring on drawing”.

The mean number of photos per trial was 4 (std = 1.7). Players were strategic in taking photos, usually taking a photo at the 0, 90, 180 and 270 compass points rather than at their starting orientation (Fig. 2d). They said I’m going to take a photo from the 4 cardinal points from where I started” or “north facing photo … south facing photo”, or photos at “each corner”. No player took a photo exactly at the start orientation and only 3 players took photos in the opposite direction to their start orientation. Taking photos encouraged players’ perusal for example one said “take a photo looking each direction; rotated clockwise from north” and they became more systematic the second time they used the device, for example “[I’m] being consistent … so I don’t get confused”. Players setting out to look for the rune mentioned various strategies. Three indicated that their initial trajectory in each trial was fairly arbitrary, for instance “north is as good direction as any.” or they had “no preferred way to go except not towards the desert area which doesn’t have any potential”. However, three made deliberate exploratory excursions, for example, “my overall strategy was to make small excursions, orientate out and back” (Fig. 2g). They did this either to scout within 3 minutes of their starting place, “I’m out here because it’s within sort of range”, or because they “don’t like the idea of moving too far away from where I was”. As the trials progressed some abandoned their exploratory excursions plan because, as one said, “its hard with no way of telling where you’ve been before” or because they felt driven to explore further, for instance “that’s a canyon … actually it looked unfamiliar so I thought I’d explore and”[I’m] going to venture further than last time”. Generally players avoided heading towards the desert, for example “I’m coming this way because it was promising because it had more greenery”. Some comments suggested players considered where the designer placed the rune, for example “he wouldn’t have put it in the valley”. This may have been based on intuiting the likely terrain of the rune’s location, for instance “I’m going on what looks promising …” and “[is]
probably just psychological but some places have no potential", or predicting the rune was deliberately occluded for instance “hid-
den behind a mountain”. However, sometimes players predicted based on their experience in previous trials, for instance “[it] probably a waste of time looking in the same place ... it is not [going to be] in the gully again” or “I’m testing how sneaky [the de-
signer] has been ... to see if he’s put it in the same place or somewhere similar”. However, they rarely felt certain about this, for example, “I think I’m wasting my time [in the canyon]”.

Players mentioned that the rune stone was hard to distinguish at a distance from “mountains” or “trees” and few climbed hills im-
mEDIATELY to identify it. For instance one said “[it] is tempting to climb mountains ... but I don’t think its worth it because if you could see it [rune] it would be worth it” Once they became familiar with the rune’s appearance they said they were looking for something “as big as a tree”. However, they still found it difficult to discern across the screen; for example, one walked past the rune visible at the edge of the screen saying “I haven’t found the rune stone yet”. As trials progressed players who missed finding the rune previously said they were, for instance, “scanning slower than last time in case that’s why I missed it” or tried to be “more structured so I can find this one”. They needed to compensate for their deviations, for instance “I had an approximate idea of my path so I wanted to check that I wouldn’t get lost by accounting for the rune stone” or, “I have to go back in that direction”.

Players did not consistently climb hills to obtain a wider view of the terrain; to remember their starting position; locate the rune stone; or, return to their starting position. Overall players climbed hills in 2/3 of the trials; however, this varied between players with one climbing hills in almost every trial and another, never climbing hills, saying “I didn’t try going up higher and having a look ... [it] just doesn’t occur to me to go high up”. One player won-
dered whether there was a threshold beyond which they could not climb, asking “How high can I go?” and another commented “going up is weird”. Two players climbed hills early in each trials, to “see what we can see” or “to get the best view”. One player men-
tioned specifically going up a hill in “looking for rune stone”. Some did this more often as trials progressed because “going up mountain to get a good view as its worked already” or became select-
IVE about the hill climbed: “going for highest mountain to give me a better view”. Some players sometimes noted landmarks that were not easily seen without elevation, for example the “dry creek bed”. One player noted landmarks from atop a hill, another drew a map, one took a photo “from the rock looking back [to where they had come from]” and one player climbed the hill to compare the

VIEW with photos taken. Gaining elevation tended to support play-
ers’ accuracy and certainty in returning to the start location but it did not assist inducing their orientation at the start location.

Hills appeared in almost all of the photos taken, as one said “taking photos of mountain structure ... only clear defining feature to orient yourself”. The terrain also influenced the number of photos taken, for example “I’m taking four photos because the area is relatively rich”. Players used the photos to return to the starting point, saying for instance “the approximate idea is to try to find something similar to where I started according to Photo 1”. They would flick through the photos to determine a direction, for exam-
ple comparing the photo with the landscape saying “Which direc-
tion was I going: did I come from?” (Figs. 2 f, g, h, i). When they determined a photo indicated their direction they would display it while proceeding in that direction; for example, “that’s where I came from ... that way... I’ll leave the photo there”. They empha-
sized recognizing the hills in the photos, for example “That [was] the rock I was standing next to” or “where’s my rock ... there it is”. However, the hills tended to occupy little of the photo, with the proportion of the photo occupied was a mean of 29% (std ev 25) and 23% (std ev 22) for the first and second trial with the photo device respectively, and ranging from 1% to 87%.

When players were close to where they thought the start location was they spent time fine tuning their position using the photo de-
vice. They compared the photos with the landscape and moved accordingly; for example “let’s stop and have a look ... right now ... that way”. Aerial views of their trajectories show many players moving within a small area or backwards and forwards along a path they thought was close to the start trying to align the land-
scape to a photo which they kept on screen continuously or alter-
ating between photos (e.g. Fig. 2 k & l). For example one said “[If I
keep doing this I’ll triangulate eventually, it’s a matter of getting the photos in the right place”. Thus, they tuned and corrected their location egocentrically, saying for example “with red rock facing right”. They generally used to hills to line up their photos with the game world, for example “just trying to get mountain in front” or “I’m too close [to a hill] let’s go backwards”. However, other more proximal landmarks were more accurate, for example one said “too close to that tree but not far off”. If they had been sys-
tematic in taking consecutive photos they would check the compass orientation, for example players said “I was looking directly south when I was doing that” or “I’m pretty close ... if I go and look west”. Players sometimes had difficulties in matching per-
spective, saying “I’m probably only a few off, but something’s not right” and might move away to “see if I’m standing in a land-
mark” or translate to check parallax for example “I needed to see if it was two separate mountains”. In time players noticed smaller details of the terrain in the photos but because they had concen-
trated on the hills to orient felt their realization was too late. Three players mentioned problems with the photo facility. One felt its size was “too big [so] its distracting”, others mentioned the pho-
tos “makes things look much further [away]” and “scale of the photo is deceptive”. Indeed, while the photo device clearly im-
proved a player’s performance they said “photos don’t help at all ... make it harder because they are a different size... my photos aren’t matching up ... lost my starting point”.

4. CONCLUSIONS & FUTURE WORK

While the photo device improved the accuracy with which the six players returned to the start location its naturalistic use did not match our expectations for behaviour in the gameworld in which it was tested. Players did not use the device to record sequences of landmarks along routes or to strengthen allocentric encoding by specifically recording information of the landmarks in the direction opposite to their outward trajectories. Rather, players appeared to try to create an extrinsic view of the world by recording a survey of their start location by linking photos to cardinal direc-
tions. However, once they had come close to their start location they tended to egocentrically match one or two photos to the ter-
rain in much the same way as insects align their encoded template to their nest [7]. We can partly account for this by the preference of all players for using a detailed map when they explore 3D games and that the compass encouraged an extrinsic FOR rather than an anchor in the world. However, this explanation cannot ac-
count for the fact that players did not consistently seek to gain
transcendent views from elevated positions to contextualize their
egocentric experience or their photos allocentrically [4].

Half the players tested undertook exploratory excursions that compare with “learning flights” [7]. We are currently extracting data from these excursions to inform designing a “rear view” de-
vice that continuously displays the view behind the player. We sug-
ject that rotating the camera to see behind is unnatural for
players in 3D visualizations projected on a 2D display because the player’s virtual body and their eyes through the camera are not integrated. The evolved navigatory behaviour of flying insects is supported by a strong optomotor system conducting optical flow information directly from the eyes to flight controllers in the legs and wings [e.g. 26, 29]. Similarly, both actively and involuntarily acquired kinaesthetic information plays important roles in human wayfinding [13]. Results suggest people best visualize locations when bodily movements are synchronised with visual cues [see: 4]; and proprioceptive interactions with terrain support encoding memories of the terrain [32]. However, the avatar in the game trials, as in most games [14], lacks feet to inform the player of relations between the camera and their forward orientation and their interactive passage is unaffected by the particulars of the terrain (e.g. wading through sand). Absent feet and unreactive terrain are legacies of urban and garden architectural principles (e.g. [36][22]), which tend to ignore the temporally evolving couplings between spatial knowledge and the physics of pathways underfoot. We will test the design of the “rear view” device in terrain that encourages couplings with physics and semantics. Players tended to use the hills as landmarks, corresponding with evidence that physically larger landmarks are prioritized for learning [14] and are recalled more easily [4]. However, large landmarks are not necessarily the most easy to distinguish en route in unfamiliar terrain [4] and it is faulty to assume that characteristics enabling recall are also “ready-to-hand” for situated wayfinding (e.g. [1]). Functionally significant features conferred distinctiveness to landmarks; for example, both the shrubs with bright berries and the logs were visually unique landmarks, but players did not note the berries for survival as they did for the logs.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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