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THE ACQUISITION OF ROUTE AND SURVEY KNOWLEDGE FROM COMPUTER MODELS

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Abstract

Two experiments were conducted investigating a series of issues concerning the nature of the spatial knowledge obtained from a computer model of a campus environment. The issues investigated were: the relative acquisition of route and survey knowledge, the construction of survey knowledge over repeated exposures, the orientation-specific nature of the cognitive representation, and practical wayfinding abilities. A series of tests were administered to assess the route and survey knowledge of subjects who learned a campus environment from a map, computer model, or direct experience. The results indicated that computer experience leads to the acquisition of some elements of both route and survey knowledge. There was also evidence of orientation specificity and functional wayfinding knowledge.

Introduction

Until recently, most studies of spatial learning have generally used either maps or direct experience as the primary means of exposure to a spatial environment. A number of studies have documented the differences associated with these modes of experience. For example, Thorndyke and Hayes-Roth (1982) compared subjects with up to 2 years of direct experience working inside an office building with those who studied a floor-plan map of the building. Map subjects were generally better at Euclidean distance and object location judgments, while direct learners were better at route distance estimates and orientation. These differences can be understood in terms of the distinction often made between route and survey knowledge (Thorndyke & Goldin, 1982). Route (or procedural) knowledge typically refers to knowledge about the movements necessary to get from one point to another. Survey knowledge refers to an integrated understanding of the layout of a space and the interrelationships of the elements contained therein. Thus, Thorndyke and Hayes-Roth's map subjects excelled on measures of survey knowledge (Euclidean distances and object locations), while their direct subjects excelled on measures or route knowledge (route distances and orientation).

Other studies have confirmed this distinction. Moeser (1988) found that subjects with up to 2 years of direct experience of a complex building had well-developed route knowledge, but their survey knowledge was inferior to map-exposed subjects. Lloyd (1989) found evidence that direct learners had to translate route knowledge into survey in order to perform element location tasks, and in doing so were slower and less accurate than their map-learning counterparts. Giraudo and Pailhoux (1994) found that subjects who learned an environment from direct navigation showed little improvement over repeated testings on an object location task while map-learning subjects did show improvement. Recently, Taylor and Tversky (1996) have also shown that when subjects learn an environment from a map, their subsequent verbal descriptions can be from either a route or survey perspective depending on the nature of the environment; however, when learning is from navigation of the environment, descriptions are far more consistently from a route perspective.

What these studies show is that direct and map learners tend to acquire different understandings of their environments. Direct learners know how to get from one place to another, although they may not know how the entire space is laid out.
Map learners have a more abstract understanding of the layout of the space, but are more likely to falter when it comes to wayfinding within it. This falls logically into line with a recent argument by Anooshian (1996) who claims that different forms of spatial knowledge are relatively independent of one another and related to the type of experience one has of the environment. In her study, when subjects learned an environment by concentrating on place locations, configurational (survey) knowledge was enhanced relative to when subjects were required to concentrate on the turns required to navigate from one point to another.

Recently, computer models have become increasingly popular as a means of environmental exposure. Intuitively, one would expect computer model experience to be similar to direct experience, and a recent analysis of spatial input modes has confirmed that they share some important features in common (although there are important differences as well; see Garling et al., 1997). Some empirical studies have supported the direct/computer connection. For example, Tlauka and Wilson (1996) found that computer model-exposed subjects showed evidence of orientation-free spatial knowledge similar to direct experience subjects and in contrast to map-exposed subjects (Thorndyke & Hayes-Roth, 1982; Presson & Hazelrigg, 1984; Presson et al., 1989). After virtual reality experience of a building, subjects tested on a point-to-unseen targets task were often just as capable as those having direct experience (see Wilson, 1997 for discussion). Studies have also shown how virtual reality experience, like direct experience, can produce extensive and accurate route knowledge but less well developed survey knowledge (Witmer et al., 1996; Ruddle et al., 1997).

Other findings, however, question the close correspondence between computer and direct experience. Theories of spatial knowledge typically contend that when survey knowledge is acquired from direct experience it is constructed in piecemeal fashion often from elements of route knowledge (Siegal & White, 1975; Golledge, 1978; Thorndyke & Goldin, 1983; McDonald & Pellegrino, 1993). This often requires extensive direct experience that accrues over years of exposure (Thorndyke & Hayes-Roth, 1982; Thorndyke & Goldin, 1983; Moeser, 1988). However, some studies suggest that survey knowledge may be acquired more quickly using computer models. For instance, Regan et al. (1992) found evidence of survey knowledge after an hour of virtual reality experience of a maze. O’Neill (1992) also found evidence of survey knowledge after subjects were exposed to computer models of different floor plans, with the complexity of the floor plan affecting the accuracy of their knowledge. Golledge et al. (1995) compared subjects who learned a building floor plan from either a map or from computer-simulated navigation. While the map subjects were generally better, the differences were nonsignificant, indicating that the survey knowledge of the two groups was roughly comparable.

What these studies suggest is that computer model experience may share commonalities with both map and direct experience. Like direct experience, computer model exposure tends to produce well-developed route knowledge. In addition, however, there is some indication that the survey knowledge of computer model-exposed subjects may be comparable to map-exposed subjects. The objective of the current study was to examine and characterize the nature of the spatial knowledge acquired from computer model exposure. The study was centered around four questions concerning computer model exposure.

**Hypotheses**

The first question of the current research was whether computer model-exposed subjects would show a general pattern of learning a route better than survey knowledge. To address this, the current study employed a battery of five tests, two designed to tap survey knowledge and three designed to assess route knowledge. Furthermore, three groups of subjects were used who experienced a single environment either by a map, a computer model, or direct experience. Though past studies have shown some ambivalence regarding computer model experience, in the current study it was hypothesized that computer model subjects would show a learning pattern similar to direct learning subjects. That is, better performance than map subjects on tests of route knowledge, but poorer performance on tests of survey knowledge.

The second question was whether the computer model subjects would show evidence of piecing together a survey representation over time. To address this, the current study used repeated exposures and testings so that the progress of spatial knowledge acquisition could be assessed. Evidence of a slow construction of survey knowledge has been found for direct learning subjects (Thorndyke & Hayes-Roth, 1982). Based on this, it was hypothesized that computer model subjects would show evidence of constructing a survey representation with increased experience.
The third question was whether computer model subjects would show evidence of orientation specificity. Orientation specificity refers to the fact that one's spatial representation has a preferred orientation. Past studies have shown that map experience usually results in orientation-specific cognitive representations while direct experience does not (Evans & Pezdek, 1980; Levine, Jankovic, & Palij, 1982; Thorndyke & Hayes-Roth, 1982; Presson & Hazeltig, 1984). One study (Tlaouk & Wilson, 1996) indicates that computer experience produces orientation-free spatial knowledge. However, it does so at a cost. The overall performance of computer subjects in that experiment was significantly worse than the map subjects. Additionally, Tlaouk and Wilson allowed subjects to actively move about in the simulated environment (subjects directed their own movements). The current study employed passive movement where a computer program directs movements about the environment. Studies addressing the active/passive distinction have been inconclusive (see Wilson, 1997, for discussion), so it was therefore unclear if this factor would make a difference in the current experiment. However, since past experiments (e.g. Thorndyke & Hayes-Roth, 1982; Presson & Hazeltig, 1984) have shown direct experience to be orientation-free and generally either better than or the same as map learning in terms of overall accuracy, the hypothesis for the current study was that computer learning should produce evidence of an orientation-free cognitive representation and the overall performance of subjects should not significantly differ from map subjects.

The fourth question was whether computer model experience would lead to successful navigation in the actual environment. If the route knowledge acquired from computer experience is to have any practical value it must allow subjects to function in the actual environment. In the current experiment this was tested by comparing the wayfinding abilities of computer model subjects to map subjects. It was hypothesized that the computer model subjects would outperform the map subjects in actual wayfinding abilities.

**Experiment 1: method**

**Subjects**

A total of 50 subjects participated in the experiment. The subjects were divided into three groups, all of whom were required to learn the layout of section of the Southeastern Louisiana University campus (U.S.A.). One group studied a map of the campus, a second group was exposed to a computer display, and a third learned from direct experience.

**Map group.** The map group was composed of 29 subjects (5 males, 24 females). There were two subgroups within the total map group. However, since the data analyses (see Results) showed that the subgroups did not differ, they were, unless otherwise indicated, treated as a single group. Twenty (four males, sixteen females) of the twenty-nine subjects were selected from the Southeastern Louisiana University subject pool and received course credit for their participation. Nine subjects (one male, eight females) were nonstudents ranging from 15–61 years of age who had no prior experience of the Southeastern campus.

**Computer group.** The computer group was composed of seven subjects (one male, six females) ranging in age from 18–53. All of them were nonstudents with no prior experience of the Southeastern campus.

**Direct experience group.** The direct experience group contained 14 subjects (7 males, 7 females), all of whom were volunteers from the introductory psychology subject pool.

**Environment**

The to-be-learned environment was the south-eastern corner of Southeastern Louisiana University (SLU), a medium-sized, regional university in the southern United States. This section of campus contained six academic buildings, along with roads, parking lots, sidewalks, trees, and other elements common to campus-like environments. Subjects were told that it was of primary importance to learn the buildings and the relationships between them.

**Exposure conditions**

**Campus map.** A map of the to-be-learned section of campus is shown in Figure 1. This map was printed in black on 8.5 × 11 inch (21.6 × 27.9 cm) paper. An 'X' next to each building marked the main entrance. The nine nonstudents of the map group were shown this map.

**Medical center map.** The campus map was submitted to both a mirror image and left/right reversal to create a second map. This map was relabeled as a fictitious medical center. The 20 Southeastern
student subjects were shown this map. For all map-exposed subjects the top of the page was considered north.

Computer display. A simulated three-dimensional computer model of the to-be-learned section of campus was created using the Virtus Walkthrough Prographics software, and displayed using a 60 mHz Pentium PC with a 15 inch full color monitor. The software program is especially designed to generate realistic environmental displays. All essential elements of the campus area including buildings, sidewalks, trees, lawns, etc. were represented.

This program also allows for ground level, walk-paced movement through the represented environment. This movement was preprogrammed as a ‘tour’ through the campus. The tour took approximately 15 min to complete. At the start of the tour, the subject was positioned at a central point south of the campus, facing north towards the campus.

The tour then took the subject for a complete walk around the perimeter of the area. It then wound around and between the buildings in order to provide experience of the campus from a variety of perspectives. Care was taken to ensure that the tour was ‘balanced’ in terms of exposure to the six buildings and the different subsections of the campus area. At no time did the tour present an overhead, maplike view of the campus. As the tour progressed, the experimenter acted as a ‘tour guide’ pointing to and naming each building as it was passed, and indicating the location of the main entrance of each building.

The seven subjects in the computer group (all of whom this were nonstudents) were shown this display.

Direct exposure. Students who were currently enrolled at the university with at least two semesters (8 months) of experience navigating the
to-be-learned section of campus were recruited for the direct exposure condition. These subjects were tested from their memory of the layout of the target campus area and were used to provide a baseline for assessing results from the other conditions.

**Tests**

Five tests were given to subjects. Two tests were designed to assess survey knowledge, while three were used to assess route knowledge.

**Survey knowledge tests.** Survey knowledge is typically defined as an integrated understanding of an environment which includes knowledge of element interrelationships (Thurndyke & Goldin, 1983; McDonald & Pellegrino, 1993). The two tests used to assess this type of knowledge were the shape recognition and configuration tests.

**Shape recognition test:** When one navigates about an environment containing large buildings such as a university campus or city business district, it is usually impossible to see an entire building in a single visual glance. Instead, to understand the overall shape of a building, one must integrate successive views from different perspectives. This is why it can sometimes be difficult to identify a complex building from an atypical perspective or from its representation on a map (see Warren et al., 1990). Since understanding a building shape requires integrating and relating separate spatial inputs into a single configuration, it represents a form of survey knowledge. To test this, subjects were presented with 14 white posterboard cut-out shapes of buildings. Six of the shapes were of the six campus buildings, while the other eight were foils. The six target shapes were the same size as those that appeared on the campus map. The foils spanned this same range of sizes running roughly from 0.6 × 2 inches (1.5 × 5 cm) to 0.8 × 4 inches (2 × 10 cm). When subjects were run individually (computer display and direct exposure conditions), the experimenter laid out the 14 shapes on a desk and asked the subject to select the shape that corresponded to each building as the name of that building was read. The experimenter then recorded the selection on a separate sheet. When testing was done in groups (map condition), each subject was given an envelope containing a set of shapes. Each shape was numbered, and subjects were told to lay the shapes out before them on their desks with the numbers exposed. Subjects were also provided with a separate sheet with six blank lines on it. The experimenter then read off the names of the six buildings and the subjects were required to write down the number of the shape corresponding to each building name as it was read. In all cases, guessing was permitted only if the subjects could narrow the selection down to two or three shapes, otherwise they were to leave that particular selection blank. After all six building names had been read, the subjects were given a final opportunity to make any changes they wished to their selections.

**Configuration test:** To test if subjects had formed an integrated understanding of the entire campus area, the configuration test was used. Using the six shapes selected during the shape recognition test, subjects were asked to arrange the shapes on a blank sheet of 8.5 × 11 inch (21.6 × 27.9 cm) white paper in the manner they felt corresponded to the buildings' actual arrangement in the environment. If six shapes were not selected during the shape recognition test, the experimenter randomly selected a shape (or shapes) to fill in for the unselected ones. Subjects were allowed to orient their arrangement from whatever perspective they wished. When completed with the arrangement, the experimenter traced around the shapes to create a permanent record of each subject's 'map' of the area.

**Route knowledge tests.** Route knowledge refers to one's ability to navigate effectively in the environment. One of the first aspects of competent navigation is to orient oneself properly and determine the correct direction of travel. To test this ability the current experiment used the direction test. The general form of the direction test was to position a subject at a certain location on the campus, facing in a certain direction and have him/her indicate the straight-line direction to a target location. Two types of direction tests were employed: a simulated test and an actual test. In the simulated test, subjects were required to imagine both their location and facing direction. In the actual test, subjects were tested from within the environment itself. Thorndyke and Hayes-Roth (1982) reported that both map and direct learning subjects performed significantly worse on simulated as opposed to actual tests. It was expected that this same pattern would occur for computer-learning subjects.

**Simulated direction test:** For the simulated direction test, subjects were asked to imagine that they were located at one of the buildings' main entrances facing either north or south. From this imagined location and facing direction, subjects were required to indicate the straight-line direction to the main entrances of the other five buildings. Trials where subjects were to imagine facing north were called
the 'aligned' trials because the north-facing direction was the same as that depicted on the maps, and it was the same as the initial facing direction for the 'tour' seen by the computer-display subjects. Trials where subjects were facing south were called 'contraligned' because this was the opposite direction as that depicted on the maps, and the opposite of the initial facing direction for the computer-display subjects. A set of aligned and contraligned trials was given for all six of the campus buildings (12 total sets). In each testing session (see Procedure section) subjects were given four sets of trials (two aligned, two contraligned) each from a different building. Across three sessions of testing, aligned and contraligned questions were administered for all of the buildings. The order to buildings across the testing sessions was counterbalanced using two opposite orders, as was the order of aligned and contraligned sets within each testing session. The order of questions within each set was determined randomly. To make their responses, subjects were given sheets of paper with five circles on them. In the center of each circle was a dot, and an arrow extending up from the dot to 12 o'clock on the perimeter of the circle. Subjects were told that the dot represented their imagined location, and the arrow was their facing direction. Subjects then made a mark along the perimeter of the circle to indicate the direction to the target building.

Actual direction test: For the actual direction test, only subjects with no prior familiarity with the university campus were used. This included all of the computer-display group and the nine nonstudents of the map group. After all laboratory testing was concluded, these subjects were tested in the actual environment. Subjects were taken to the main entrances of four buildings and asked to indicate the straight-line direction to the main entrances of

![Diagram](image_url)

**Figure 2.** A graphic representation of the relative centerpoint error measure. Three buildings are shown (for purposes of demonstration the buildings have been enlarged and printed out in landscape rather portrait orientation). The buildings are shown with the bold, darker lines. The four corners of the buildings are joined to create a rectangle and lines bisecting each line of the rectangle are drawn to find the centerpoint. This is shown with the lighter, thinner lines. Vectors (labeled A and B) are then drawn connecting the building centerpoints. Vectors A and B can be measured in terms of the angle (in degrees) and distance (in inches). These vector measurements can then be compared to those obtained from a subject's reconstructed map.
the other five buildings. At two of the buildings, subjects faced north (aligned), and at two they faced south (contraligned). The buildings chosen for testing were ones that provided no visual access to the other buildings as the test was being done. Subjects used a hand-held pointer, which had an adjustable arm on it, mounted within a circular dial marked out from 0 to 359 degrees. At each main entrance the experimenter faced the subject in the appropriate direction and asked the subject to adjust the pointer arm to point directly at the main entrances of the other buildings. The experimenter then copied down the degree setting for each response.

**Wayfinding test:** The same subjects who received the actual direction test were also tested on wayfinding. After a direction test was completed at one building, the experimenter informed the subject that they were going to walk to the main entrance of another building. The subject was asked to lead the way to the main entrance of the next building. If the subject was able to find the way to the next building and locate the main entrance with no help from the experimenter, the response was considered correct. An error was scored if the experimenter had to stop the subject and redirect him/her back towards the goal (this was done only if the subject was heading badly off course or was in danger of wandering off the campus) or if the subject indicated that he/she did not know where the goal was and needed help. The subject traveled to three buildings' main entrances during the course of the testing. The subject was allowed to make a maximum of two errors on any one route before the experimenter intervened and led the subject to the goal. Thus a total of six errors was possible on the test.

**Dependent measures**

The shape recognition test was scored with a simple proportion correct. The configuration test was scored using a procedure similar to that of Golledge et al. (1995). This was done in the following way. The centerpoint of each building was identified; this was defined as the centerpoint of the rectangle created by joining the four extreme corners of a building with straight lines. Vectors were then identified that joined all of the building center-points. The angle of each vector (in degrees) and the distance (in inches) were measured. The set of angles and distances for each subject's map was then compared to the correct angles and distances. (Since subjects had already received a score for their accuracy on identifying building shapes, no penalty was assessed on the configuration test if the subject had an incorrect shape or shapes on their maps.) An overall mean angle and distance error score was obtained for each subject's map. A graphic example of this is provided in Figure 2.

The direction tests were scored using an angle error measure. This was the absolute value difference between the subject's response angle and the correct angle. A mean angle error was obtained for both aligned and contraligned trials. The wayfinding test was scored using the total number of errors committed by each subject.

**Procedure**

**Map subjects.** Map subjects were tested either in classrooms on campus (students) or at a residence off campus (nonstudents) in groups of four or five. The subjects were given a copy of the map and told they would have 2 min to study it, after which they would be given a series of tests measuring what they had learned. After 2 min, the map was removed and subjects were given the shape recognition test, the configuration test, and the simulated direction test (in that order). When all three tests were completed subjects were allowed two more minutes of study, after which the tests were repeated. Three sessions of studying and testing were done. After this testing was concluded, the nonstudent subjects were driven to the campus and were individually administered the actual direction test and the wayfinding test.

**Computer-display subjects.** To ensure that these subjects would not receive any incidental exposure to the campus, each was met individually by an experimenter at a location near but off campus. The subject was escorted to the testing location on campus and was required to look down at the sidewalk until inside the testing building was located at an extreme corner of the campus and did not require having the subject walk onto the campus to any significant degree. Once in the testing building, the procedure for the computer-display subjects was the same as the map subjects except that they were run individually, and four testing sessions were used rather than just three. A fourth session was included in order to provide a total of an hour of exposure time, thus equalling the amount of exposure time used in the Regan et al. (1992) study. Evidence of survey knowledge acquisition was found for computer-exposed subjects. These subjects were also tested in the environment after the fourth session.

**Direct learning subjects.** Each subject was run individually. First, the subject was given a very brief
questionnaire to determine how much time he/she had spent in the to-be-learned section of campus. (Results showed that on average subjects had just under 2 years of direct exposure with a range of 8 months to 4 years.) Then the subject was administered each of the tests, in the same order as the other conditions. Since there was only one testing session, this meant that subjects were administered all 12 of the aligned and contraligned sets of the direction test at once.

Results and discussion

Analysis procedure

For each test, the same procedure was used in analysing the data. First, the two map subgroups were compared to determine if there were any significant differences between them. (To foreshadow, in all cases there were no differences, and the groups were combined.)

Second, the map and computer-display subjects were analysed separately across sessions to determine how their knowledge developed over time. Furthermore, given the small sample size of the computer group, all general trends were confirmed on an individual subject basis.

Third, across-group comparisons were done (map vs computer vs direct) to determine how different modes of experience affected the spatial knowledge obtained. Across-group comparisons were not straightforward given the large sample size differences of the three groups. In all cases an effect was only deemed significant if it reached an alpha level of 0.01, and for any post hoc comparisons, a 0.001 alpha was used.

Finally, the two groups unfamiliar with the to-be-learned environment (the nonstudents of the map group and the computer display group) were compared on the actual direction test and the wayfinding test.

Shape recognition test

Map subjects across sessions. A one-way WS ANOVA (sessions as IV) was run on the proportion of correct scores for the shape recognition test. The top (solid) line of Figure 3 shows the mean scores across sessions for the map subjects. The effect of sessions was significant \( F(2,54) = 26.3, \ p < 0.001, \ M\text{Se} = 0.04 \) and strong (omega squared = 0.29).

Computer subjects across sessions. The bottom (dashed) line of Figure 3 shows the mean scores for the computer subjects across sessions. The effect of sessions was significant \( F(3,18) = 16.5, \ p < 0.001, \ M\text{Se} = 0.02 \) and very strong (omega squared = 0.53). Because of the small sample size of the computer group it was important to determine if the overall trend was truly reflective of individual subjects. The overall trend showed progressively increasing scores across sessions. Five of the seven subjects showed precisely this same trend, while two showed this trend in general, but with one decline in scores across sessions. There are a number of points to emphasize concerning the effects shown in Figure 3. First, note the relative starting points of the two groups. After 2 min of study the map subjects recognize 40 per cent of the building shapes, while after 15 min the computer subjects recognized less than 20 per cent. Second, note how the computer subjects consistently run about 20 points behind the map subjects across sessions. Third, by the last session both groups have nearly the same mean score. However, to reach this point required 6 min of exposure for map subjects compared to 1 h of exposure for computer subjects. Computer subjects can and do learn shapes to a point equalling map subjects, but the amount of exposure necessary to acquire the same information is much greater.

Group comparisons. The first session mean for map and computer subjects was compared to the score of the direct subjects (the dot at session 1 represents the mean for the direct subjects). Because map and computer subjects were given repeated testings,
subjects may have intentionally directed attention to the building shapes after session one. Therefore, only the session one score for map and computer subjects is directly comparable to the score for the direct subjects. A one-way BS ANOVA using type of experience as the IV was run on the data. Because of the large differences in sample size across groups, effect was considered significant only if it exceeded an alpha level of 0.01. By this criterion the effect of experience was nonsignificant \( F(2,46) = 3.2, p = 0.05, \text{MSe} = 0.05 \). The mean scores for the three conditions were as follows: map = 0.40, direct = 0.26, computer = 0.19.

**Configuration test**

**Map subjects across sessions.** Two measures were taken from the configuration test; the angle error (in degrees), and the distances error (in inches). The bottom (solid) lines in Figure 4 show these measures for the map subjects. Both measures showed a significant sessions effect: angle error \( F(2,54) = 5.8, p = 0.005, \text{MSe} = 0.5 \); distance error \( F(2,54) = 19.0, p < 0.001, \text{MSe} = 0.5 \).

**Computer subjects across sessions.** The top (dashed) lines of Figure 4 show the results for the computer subjects. In contrast to the map subjects, the effect of sessions for both measures was nonsignificant. This may seem a little surprising for the angle error measure given the large decrease from session 1 to 2. However, while confirming if the overall trend was reflective of the individual subject’s performance, it was found that one subject accounted for the relatively high session 1 score. This subject had a session 1 score of over 100 degrees. Without that subject, the average session 1 score was 31.3, very much in line with the other sessions. The remaining subjects show no clear upward or downward trend across sessions.

The results from the configuration test are clear. Map subjects learn more about the configurational properties of the campus and they continue to learn with increased exposure. Computer subjects learn less, and they acquire very little with increased

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**Figure 4.** A graph showing the average angle error (left) and average distance error (right) on the configuration test for the map subjects (—), computer subjects (·····), and direct subjects (○).
exposure. The lack of improvement for computer subjects replicates the previous results of direct navigation subjects (Giraundo & Pailhous, 1994).

**Group comparisons.** For the same reason discussed earlier with the shape recognition test, the first session scores for map and computer subjects were compared to the scores for the direct subjects. (Direct subjects’ scores are represented as dots in sessions 1 in Figure 4.) A one-way BS ANOVA (experience as IV) was run on both the angle error and distance error scores. In both cases the results were the same. The effect of experience was significant (angle error: $F(2,46)=5.7$, $p=0.006$, MSe = 420.8; distance error: $F(2,46)=12.7$, $p<0.001$, MSe = 0.16). Simple $F$ tests were used for post hoc comparisons; however because of different sample sizes a 0.001 alpha was used for significance. Post hoc comparisons showed the same pattern for both measures; that was, the mean score for the map group was significantly less than that of the direct group. No other comparisons were significantly different.

As with the shape recognition test, these results are fairly clear. Map subjects acquire the most accurate configurational knowledge of the environment while direct subjects acquire the least, with computer subjects somewhere in between. It should be noted that these results replicate those of Golledge et al. (1995) who, using similar angle and distance error measures, found somewhat better performance for map learners compared to computer-display learners though the differences did not reach significance.

**Simulated direction test**

**Map subjects across sessions.** The solid lines of Figure 5 show the map subjects’ mean angle error scores across sessions for aligned and contraligned trials. These scores were analysed using a 2 (alignment condition) × 3 (session) WS ANOVA. A significant main effect of sessions was found [$F(2,54)=3.2$, $p=0.05$, MSe = 460.8] indicating a general, modest, improvement in scores across sessions (overall means for sessions, respectively, were: 77-8, 73-7, 67-4). A significant alignment condition main effect was also found [$F(1,27)=70.6$, $p<0.001$, MSe = 2936-1]. The mean contraligned score (105-2) was significantly higher than the mean aligned score (37-9). The interaction of alignment condition and sessions was nonsignificant.

**Computer subjects across sessions.** The dashed lines of Figure 6 show the computer subjects’ mean aligned and contraligned scores across sessions. These scores were analysed using a 2 (alignment condition) × 4 (sessions) WS ANOVA. Only alignment condition showed a significant effect [$F(1,6)=6.0$, $p=0.05$, MSe = 3344-7]. The mean contraligned score (86-6) was significantly higher than the mean aligned score (48-8).

**Group comparisons.** Since session 4 for the computer subjects was a repeat session (they received the same trials as they received in session 1), the session 1 through 3 aligned and contraligned scores for map and computer subjects were compared to the aligned and contraligned scores for the direct subjects (direct subjects received all 12 aligned and contraligned sets in one session). Figure 6 shows...
these scores. Two significant effects are apparent in the figure. A significant alignment condition × experience interaction was found \( [F(2, 46) = 13.5, p < 0.001, 	ext{MSE} = 2530.0] \). The nature of this interaction is clear from the figure. For map and computer subjects contraligned scores are significantly higher than aligned scores. For direct subjects there is no difference. An alignment condition main effect was also found, however this effect is obviously subordinate to the interaction.

**Sex effects**

The across-groups comparisons suffered from a potential confound. The map and computer groups were equivalently disproportionately female (83% female for map group, 86% for computer group), while the direct experience group was balanced for sex. Thus, it was important to assess what impact this may have had on the stated results and conclusions. Analyses of sex effects in the direct group were carried out for all of the dependent measures. On all measures except one, there were no significant differences between males and females. On the distance error measure of the configuration test, males \( (M = 1.2) \) were significantly more accurate than females \( (M = 1.8) \). This finding, though, does nothing to change the results and conclusions previously stated. Direct subjects were found to be significantly worse than other groups on this measure, in spite of the fact that they had more male subjects than the other groups. If all groups had been balanced or equally proportioned for sex, one would expect even larger differences between groups than those replicates past literature (e.g. Golledge et al., 1995) which found the same.

**Actual direction test**

As stated earlier, the two groups unfamiliar with the to-be-learned section of campus (the computer display group and the nonstudents of the map group) were given the direction test in the actual environment.

The aligned and contraligned error scores for both map-exposed and computer-exposed subjects were analysed using a 2 (type of experience: map vs computer) × 2 (alignment condition) mixed ANOVA (experience was the BS variable, alignment condition was WS). Though this analysis showed no significant effects, it is still interesting to note that the map subjects showed a difference between aligned and contraligned error scores (aligned = 28.2, contraligned = 36.3), while computer subjects did not (aligned = 22.1, contraligned = 21.4).

**Wayfinding test**

The number of errors committed while traveling to buildings was analysed using a one-way ANOVA, with experience as the variable. A significant effect of experience was found \( [F(1, 4) = 4.4, p = 0.05, 	ext{MSE} = 1.7, \text{omega squared} = 0.18] \). The mean number of errors committed by the map subjects (2.1) was significantly higher than that of the computer subjects (0.7). A subject analysis shows how substantial this effect was. Of the nine map subjects, eight committed at least one error, and six committed two or more. Of the seven computer subjects, all of the errors were concentrated in two subjects, as five of the seven committed no errors.

Though the results paint a fairly clear picture of the types of knowledge acquired by map, direct, and computer experience, one important issue remains unresolved. The first experiment indicated that the spatial knowledge acquired from computer experience was orientation-specific (subjects were more accurate on aligned vs contraligned trials of the simulated direction test). There is reason to question this finding. Since a single order of test administration was used, all subjects responded to the direction test after having constructed a 'map' of the campus. Computer subjects may have been using map information (rather than that acquired from the computer tour) as a basis for answering questions on the direction test. Since most of the computer subjects constructed their maps from a 'north is up' perspective, it is not surprising that their performance was better on aligned vs contraligned questions. A second study was designed to address this potential problem.

**Experiment 2**

A second experiment was designed to directly assess the extent to which spatial knowledge obtained from computer display experience exhibits orientation specificity. For Experiment 2, a different campus environment was used. The extreme western end of the University of California Riverside (UCR) campus served as the to-be-learned environment. Like the SLU campus, the UCR campus contains six buildings, along with sidewalks, trees, lawns and other elements common to campus-like environments. The campus area was represented using both maps and a computer display. The maps of the
campus were designed to follow the same principles as those used in Experiment 1. The maps were printed in black on 8.5×11 inch paper. An ‘X’ was used to indicate the main entrance of each building. The computer display was also designed to follow the same principles as that used in Experiment 1. The same software (Vertis Walkthrough Pro) was used to create the display. The campus ‘tour’ was designed to be balanced among the six buildings with the area viewed from a variety of perspectives. The tour ran slightly longer than the one used in Experiment 1 (about 20 min) and it started from a position north of the campus facing south, rather than vice versa as was the case for the tour in Experiment 1. (Thus, ‘aligned’ for map subjects was north-facing, while ‘aligned’ for computer subjects was south-facing.)

A new direction test was also developed for Experiment 2. It followed the same guidelines described in Experiment 1. In Experiment 2, however, the direction test was the only test given to subjects after their exposure condition.

Procedure

Thirty-six new subjects were recruited for Experiment 2. Twenty-four subjects studied maps of the campus (12 males, 12 females). Twelve subjects (6 males, 6 females) studied the computer display. The map subjects were tested in groups of one to four subjects. After the experimenter described the study to them, the subjects were allowed 2 min to study their map. When the 2 min were up, the maps were removed and subjects were given the direction test. This study/testing procedure was repeated three times for a total of 6 min of study.

The computer subjects were tested individually, in the same manner as described for Experiment 1. Unlike Experiment 1, however, immediately after their computer exposure, they were given the direction test. No other tests were administered. Subjects were given three sessions of computer exposure and testing (for a total of 60 min of exposure).

Results and discussion

Figure 7 shows the data for both the map and computer display subjects. Since the goal of Experiment 2 was to assess orientation specificity in computer subjects, a detailed analysis of the map subjects was superfluous. However, Figure 7 shows the similarity of the two groups, and analyses revealed a significant effect of alignment condition for both map subjects [$F(1,22) = 14.3, p = 0.001, MSe = 2615.8$], and computer subjects [$F(1,10) = 7.1, p = 0.02, MSe = 3066.9$]. In both cases the average contraligned score was significantly higher than the average aligned score. Based on these data, one can only conclude that the spatial knowledge of the computer subjects was no less orientation specific in nature than that of the map subjects.

General discussion

The four questions that drove this research can now be answered.

*Question 1: Do computer subjects show a general pattern of learning route better than survey knowledge?*

Before discussing the computer subjects it is important to note that the current research replicates previous findings showing that map subjects acquire better survey knowledge while direct learners acquire better route knowledge. Map subjects outperformed direct subjects on both tests of survey knowledge. Map subjects had a higher proportion correct on the shape recognition test and significantly lower error scores on the configuration test. When it came to orienting ability, however, direct subjects were equally accurate from either a north-facing or south-facing perspective while map subjects showed strong evidence of orientation specificity on the simulated direction test.

With regard to computer subjects, it was hypothesized that they would show a pattern of learning
similar to direct subjects; that is, better performance than map subjects on tests of route knowledge, and poorer performance on tests of survey knowledge. The results show some tendency toward this pattern but it is far from clear-cut. As expected, on the two tests of survey knowledge the performance of computer subjects was inferior to the map subjects. Computer subjects had the worst initial score on the shape recognition test (0.19, compared to 0.26 for direct and 0.40 for map subjects), however they improved significantly over sessions to a point nearly equaling the map subjects. On the configuration test, though their scores were worse than map subjects (as predicted), the difference was not significant. However, while map subjects improved over sessions, computer subjects did not.

The route knowledge tests also produced mixed results. On both actual and simulated direction tests, contrary to expectations, the computer subjects were no better than map subjects. Both map and computer subjects were better on actual compared to simulated tests, thus replicating the findings of Thorndyke and Hayes-Roth (1982). When it came to wayfinding ability in the environment itself, however, computer subjects were significantly better than map subjects.

These results suggest that elements of both route and survey knowledge are acquired from computer model experience and this is consistent with some past findings (e.g. Regain et al., 1992; Witmer et al., 1996). What type of knowledge is acquired may very well be affected by a variety of factors associated with the specific environment depicted, the manner of exposure, and the assessment measures used. For instance, O'Neill (1992) showed that the complexity of the environment can affect subjects' ability to acquire survey knowledge. In the current study, when survey knowledge was assessed by the recognition of overall building shape, computer-model subjects showed significant improvement over time. However, no improvement was shown when survey knowledge was assessed by the ability to accurately construct the relationships among the total set of buildings. Additionally, the current study employed passive rather than active movement. This may have had an impact on the acquisition of the orienting aspect of route knowledge.

**Question 2: Do computer subjects show evidence of piecing together a survey representation?**

It was hypothesized that computer subjects, like direct learning subjects, would construct survey knowledge over repeated exposures. The answer appears to be that it depends on the complexity of what is being constructed and how the knowledge is tested. Computer subjects improved in their ability to recognize the correct overall shapes of buildings. However, they showed no improvement in their ability to accurately represent the spatial relationships among the buildings. The latter was, in all likelihood, a more challenging integrative process. Although past research has shown that survey knowledge of a maze could be acquired after an hour of computer exposure (Regain et al., 1992), it may be that this was not enough time to construct an overall campus representation. It could also be that under some circumstances survey knowledge is never constructed. While Thorndyke and Hayes-Roth (1982) found evidence of accurate survey knowledge of an office building for subjects with 2 years of direct experience, Moeser (1988) found no evidence of survey knowledge in subjects with the same amount of experience in a hospital complex. Computer-model experience, like direct experience, may or may not lead to survey knowledge depending on a host of factors including the complexity of the environment to be learned.

**Question 3: Do computer subjects show evidence of orientation specificity?**

It was hypothesized that computer-model subjects, like direct learners, would not show orientation specificity. This hypothesis seemed especially secure in light of the recent findings by Tlauka and Wilson (1996). Surprisingly though, evidence of orientation specificity was found in Experiment 1, and replicated in Experiment 2 when using a simulated direction test. The active/passive movement difference between the current study and the Tlauka and Wilson study may be an important factor in mediating this effect. This finding replicates a previous finding using maps (Presson et al., 1987) where subjects were allowed multiple views of a map, but showed evidence of an orientation specific map representation corresponding to the first view studied. The orientation preference for the current computer subjects also corresponded to the initial view of the environment. This suggests that like map experience, computer model experience may involve a 'first view priority' where the initial view becomes the basis for organizing the spatial representation of the environment.

Evidence of orientation specificity was, however, restricted to the simulated test. On the actual direction test, there was no evidence of orientation
specificity and generally accurate performance. This replicates the findings of Thorndyke and Hayes-Roth (1982). In that study, the authors explained the poorer performance of subjects on simulated tests by citing the additional mental burden imposed by having to imagine locations and facing directions. This may also account for the difference in the computer subjects' performance in the current study. The first view may be the most easily accessed view under conditions of high cognitive load.

**Question 4: Does computer model experience allow for effective wayfinding in a novel environment?**

It was hypothesized that computer experience would be an effective wayfinding tool, and it was. Though they had never been on the campus before, five of the seven computer model subjects were flawless in their ability to navigate from one specific location to another. In total the computer group committed significantly fewer wayfinding errors than the map group. Witmer et al. (1996) demonstrated that subjects who had virtual reality experience were more capable of navigating through a building than those given verbal instructions supplemented with photographs. The current study replicates and extends those findings by showing how computer experience can be equally effective in larger, more open environments as well as superior to map experience. Indeed, many of the computer subjects reported feeling very confident in their ability to find their way around the campus, and also indicated a sense of familiarity (as if they had 'been there before') when tested in the actual environment.

With the increasing availability of powerful personal computers, the potential for ‘visiting’ a distant place before actually going there is greatly increased. The current research shows how this type of experience may prove even more beneficial than map experience. The apprehension about visiting faraway places as well as the very real potential for getting lost can be mitigated by prior computer-simulated experience.

A cautionary note is in order when interpreting these findings. Though the computer group of the current study was diverse, it was also a relatively small sample. The group contained a mix of ages including high school students (age 18), young adults (in their 20s and 30s) and older adults (40s and 50s). Education levels also varied from those with college degrees to those with little or no college experience. The results of the current study were fairly consistent both within the group itself and with past studies, which suggests the potential for wide generalizability. However, caution is always wise when groups are small.

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**Notes**

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Route and Survey Knowledge


