Cognitive Maps in Virtual Environments: Facilitation of Learning Through the Use of Innate Spatial Abilities

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ABSTRACT

It is often difficult for people, and particularly children, to learn relationships between data points (such as the relative sizes of the planets of the solar system). This sketch introduces a study aimed at investigating whether this type of data can be more easily learned by presenting it within a Virtual Environment, where the relationships between data points is represented by equivalent spatial relationships. By converting data relationships to spatial relationships, we are able to use our innate spatial abilities to understand and remember the data. The data is thus converted from an external form, to an internal representation that is always to hand and which is mentally easy to deal with.

Keywords

Categories and Subject Descriptors: I.3.7 [**Computer Graphics**]: Virtual Reality.

General Terms: Human Factors, Experimentation

Additional Key Words and Phrases: virtual reality, visualization, teaching, presence, navigation, cognitive maps, spatial

1. INTRODUCTION

With the use of Virtual Environments, information can be presented in truly 3-dimensional form, allowing users to enter into the data and study relationships close up. This type of presentation has mainly been used for complex scientific visualizations, but until now has not been considered for use in teaching. This sketch shows how it has great potential for use amongst schoolchildren and the general public. By representing data in a spatial form, with spatial relationships between objects in a VE representing the relationships between data items, we can represent almost any set of data in a spatial form, whether it is spatially based or not. For example, a database of famous composers could be spatially represented within a VE by representing each composer with a statue, with the distance between composers indicating the degree of similarity of their music styles. By using spatial hyperlinks, or *teleports*, different sets of spatial relations can be created for the same data set – so in our composers example, teleports could be set up to link statues in a temporal relationship in addition to the similarity of style relationship. In such a VE, the geography and environmental features are based on data items and the relationships between them.

This is a useful way of presenting data to be learned. By setting up data relationships as spatial relations, we make use of the brain's well-developed spatial abilities. Just by exploring such a VE, the visitor is subconsciously acquiring knowledge about the layout of the environment – and thus also knowledge about the data items relate to each other. This occurs because when people move around new environments, whether they are real or virtual, they subconsciously build a mental image of the space they are in [3]. This mental image is encoded in the hippocampus [1], and is called a "cognitive map" [7, 10, 12]. It helps people find their way in environments that they have visited before, and also helps them remember the structure of the place, for example if they are asked for directions [3].

This method is fundamentally different from normal visualization techniques, both in terms of its aims and methods. Visualizations are normally applied to mathematical structures and models, and users of scientific visualization are usually experts [4]. They aim to provide insight into complex phenomena, and to allow users to make inferences from the data provided. The spatial teaching method, however, can be used to display many types of data for which visualization is not normally required (for example, the order of the planets in terms of distance from the sun), and is primarily concerned with helping a student to remember the data layout for later recall. In visualizations, the viewer stands apart from the data, looking at a small picture on a screen in front of them, whereas in the VR teaching technique participants are immersed in the environment created by the data, and are physically surrounded by objects as large as they are.

This sketch describes a study in progress which aims to investigate the effectiveness of using this spatial method for teaching, as well as exploring some other central factors, such as the effect of the display type of the VE and the type of navigational aids given to participants.

2. RELATED WORK

It often helps to know locations if we want to memorize events, people and things [7]. Cognitive maps are a way to structure and store spatial knowledge [7], allowing the "mind's eye" to visualize images in order to enhance recall and learning of information [2]. Spatial thinking can thus be used as a metaphor for non-spatial tasks, where people performing non-spatial tasks involving memory and imaging use spatial knowledge to aid in processing the task [7]. While this study is the first to use Virtual Reality technology, the idea of using spatial information to learn data is not new. For example, the spatial arrangement mnemonic suggests that lists of words are more easily remembered when they are arranged in a distinctive spatial pattern than when they are presented as a list, and that when students used a link mnemonic to memorize these lists they recalled significantly more words than those who memorized them using conventional techniques [2].

The oldest known method of using spatial locations to remember data is the "method of loci". This method was originally used by students of rhetoric in Ancient Rome when memorizing speeches. To use it one must first memorize the appearance of a physical location (for example, the sequence of rooms in a building). When a list of words, for example, needs to be memorized, the learner visualizes an object representing that word in one of the pre-memorized locations. To recall the list, the learner mentally "walks through" the memorized locations, noticing the objects placed there during the memorization phase [2].

More recently, Kitchin [7] suggests that a thorough understanding of how cognitive maps are formed will help to improve database design and efficiency, particularly for GIS applications.

Spatial relationships can also be used in deriving logical inferences. Premises are transformed into internal representations, such as an array with spatial properties. Manipulation of this spatial array can lead to the solution of transitive inference problems [4].

3. COGNITIVE MAPPING THEORY

Central to this spatial theory of teaching is the concept of forming a mental image of a space. This process is called "cognitive mapping", and the mental image formed is known as a "cognitive map" [7, 10]. A cognitive map is essentially a network of representations coding both the places and the sequential relations between them [10]. It is a mental construct we use to understand and know environments, which can be used to make spatial decisions [7].

When forming a cognitive map, the mind uses certain heuristics to simplify both the formation and the storage of the cognitive map [12, 13]. For example, objects are often grouped together in a hierarchy – cities are grouped together into a country. Using these sorts of heuristics allows the brain to simplify the cognitive map to be stored, by making use of simplifying assumptions. However, these assumptions may not always be correct, and so the use of heuristics can often reduce the accuracy of the stored cognitive map. For example, if items are grouped into one entity, then the relationships between that entity and another entity is assumed to hold for all objects in those entities [9, 12]. So if Canadian cities are grouped to form "Canada", and American cities are grouped to form the US, then because the US is south of Canada it is assumed that all cities in the US are south of all cities in Canada [9] – which is clearly wrong in the case of Seattle and Montreal, as can be seen in Figure 1.

Unfortunately, it has been shown by a number of studies that these distortions in the cognitive map occur regardless of whether the map is of a real place or a virtual one [9]. This obviously presents an obstacle to the idea of displaying data sets in a spatial form so as to utilize one's spatial abilities for learning. However, when the causes of the distortions are understood, virtual environments can be built not only to overcome these distortions, but actually to make use of them. For example, roads with lots of bends and turns are generally perceived as being longer than straight roads of equal length [10]. Two objects can thus be placed close together, but joined via a winding route to give the impression of a greater distance.

In order to study the cognitive map that someone has built up, we need to obtain an external representation of it. This is usually done by means of a *sketch map* – the participant is given a blank piece of paper and asked to draw the environment that they have experienced. The researcher then analyses the sketch map in several different ways in order to extract information from it.

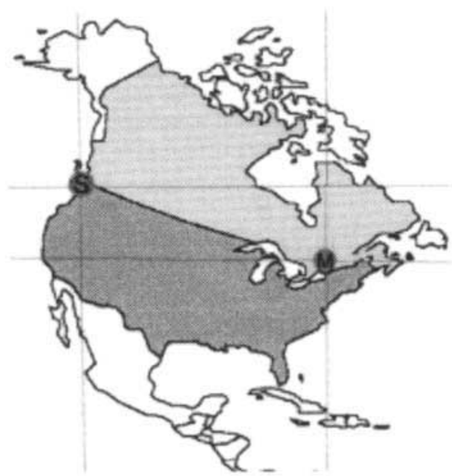

Figure 1: A map of North America showing the relative positions of Seattle (on the left) and Montreal (on the right).

4. DESIGN

This study aims to discover whether the spatial abilities of the mind can be used to teach relationships between non-spatial data items. By internalizing data that is normally only external, we provide the mind with a tool to mentally manipulate data in a natural way.

There are certain criteria that this method must fulfill before it can be considered to be useful teaching mechanism. It must be at least as effective as conventional teaching methods, and it must be enjoyable. Preferably, it should be effective on a desktop display, as this will enable it to be more widely used (immersive HMD systems are very expensive). We would also like it to be effective regardless of the spatial abilities of the participants.

There are thus five main questions that this study aims to answer:

Q1: Is learning:
  a) more enjoyable
  b) more accurate (or at least as accurate)
in VR as opposed to normal methods?

Q2: Is there a difference in
  a) accuracy of learning
  b) accuracy of cognitive mapping
  c) way-finding ability
  d) presence
when using a head-mounted display as opposed to using a desktop display?

Q3: Does the type of map provided to subjects (i.e. impressionistic sketch map, veridical cartographic map, or no map) affect:
  a) accuracy of learning
  b) accuracy of cognitive mapping
  c) way-finding ability

Q4: Is there a relationship between the participant's sense of presence and their accuracy of learning?

Q5: Is there a relationship between the participant's spatial abilities and their accuracy of learning?

These 5 questions will be answered using a 2 x 3 factorial design [11] on map type and display (for Q2 and Q3) and using a 1-way ANOVA [11] on teaching method (for Q1), while Q4 and Q5 will be tested using a simple correlation. In essence, then, there will be 3 separate studies, but with one set of subjects.

Choosing an operationalisation for variables is always difficult – one can never truly encompass all facets of a variable with just one or two measures. This is particularly true for contructs such as "accuracy of learning". This study has thus adopted the simple approach of giving the subjects a short test on the subject material. This allows for quantitative analysis of the data obtained.

4.1 Study 1: The Effect of Map and Display Types

The first study will focus on the effect of map type and display type, and will be run as a 2 x 3 factorial design (2 display types, i.e HMD and desktop, and 3 map types, i.e. cartographic map, sketch map, and none). Following statistical procedure, there will 8 participants per cell, for a total of 48 (see Figure 2).

The independent variables in this study are:

- enjoyment (as measured by the Differential Emotions Scale[6]);
- accuracy of learning (as measured by analysis of sketch maps drawn by participants, as well as a test on the subject material);
- accuracy of navigation (as measured by a way-finding score such as number of wrong turns, and time taken);
- presence (as measured by Witmer & Singer's PQ)
- accuracy of cognitive mapping (as measured by analysis of sketch maps and distance judgement tasks)

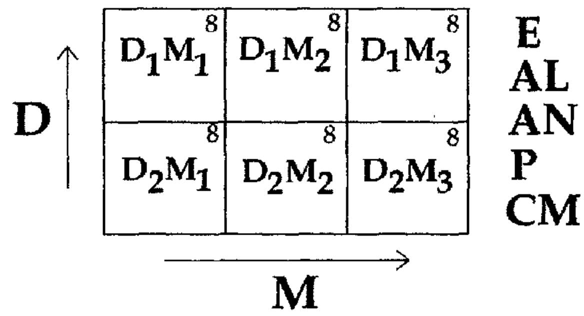

Figure 2: Study design for testing the effect of map and display types on enjoyment, accuracy of learning, accuracy of navigation, presence, and accuracy of cognitive mapping.

4.2 Study 2: The Effect of Presence and Spatial Abilities on Learning via the Spatial Method

This will be a fairly simple study, consisting of correlations between presence and accuracy of learning, and between spatial abilities and accuracy of learning.

There will be 48 subjects in total, and the variables will be measured as in Study 1. Spatial abilities will be measured in a post-test questionnaire, incorporating questions testing the ability to mentally rotate objects, as well as the ability to mentally rotate and translate oneself. The questionnaire also includes the self-report Everyday Spatial Abilities Test [8].

4.3 Study 3: The Effect of Teaching Method

This study will take the form of a 1-way ANOVA on teaching method, thus comparing the spatial, VR method with more traditional methods of teaching (such as a webpage, lists of facts, and videos).

There will be three cells (1 for the VR method, and 2 for conventional methods), with 8 subjects per cell (i.e. 24 in total) – see Figure 3). The subjects for the two conventional methods will not have participated in the previous studies; the subjects for the VR condition will be those from the map type / display type combination from Study 1 with the best accuracy of learning results.

The independent variables in this study will be:

- enjoyment (as measured by the Differential Emotions Scale [6])
- accuracy of learning (as measured by analysis of sketch maps drawn by participants, as well as a test on the subject material)

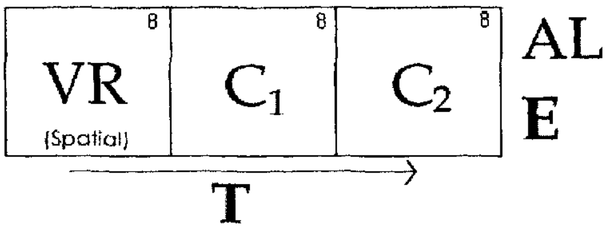

Figure 3: Study design for the testing the effect of teaching method on accuracy of learning and enjoyment, with 8 subjects per cell.

4.4 Running the Experiments

Subjects will be recruited across campus, with an emphasis on students from the Computer Science and Psychology departments (as these students are most accessible). Subjects will thus be volunteers, and will be paid.

Subjects will be divided into 3 groups – 48 for VR, and 8 each for the two conventional teaching methods. Within the VR group, each of the 48 subjects will be randomly assigned to one of the six conditions:

- sketch map \ desktop
- cartographic map \ desktop
- no map \ desktop
- sketch map \ HMD
- cartographic map \ HMD
- no map \ HMD

Each of these conditions will thus have 8 subjects.

Participants will have to spend a reasonable amount of time in the Virtual Environment in order to build up a cognitive of the virtual space. In addition, they will have to explore the environment fully in order to cement their ideas of where things are in relation to each other. To facilitate these two goals, they will be given a task to perform in the VE. This task will involve finding objects scattered around the environment, which they will have to collect in order. This will force them to take note of the location of objects, and return to these locations when required (something like a 3-dimensional game of "Memory").

Before beginning the experiment, each participant will be introduced to the equipment they will be using, and will be given an opportunity to practice moving around in the Virtual Environment. The practice area will be part of the experimental VE, but will be in the form of an "ante-chamber" – participants will not be able to access the experimental section of the VE during the practice session. During this session, the task will be explained to the participant, and they will be allowed to practice picking up objects. They will also be shown the effects of trying to pick up objects in the wrong order, so that if this occurs during the experiment, they will know what is causing the effect that they are seeing. When the participant indicates that they are comfortable with the equipment and with interacting with the VE, they will be allowed to enter the experimental area of the environment and the experiment will start. In the HMD conditions, an observer will stay in the room in case any difficulties arise (e.g. simulator sickness or hardware failure), while in the desktop conditions an observer will remain outside the room so as not to decrease the sense of immersion felt by the participant.

After completing the task (or spending a minimum amount of time in the VE, if it appears that the participant will not be able to complete the task successfully), participants will leave the VE (in the HMD conditions, this will be prefaced by a visual warning, so as to prevent any disorientation). They will then be asked to fill in a questionnaire (covering biographical data, a spatial abilities test, the Presence Questionnaire, and an enjoyment questionnaire). They will be asked to draw a sketch map of the virtual environment, and to perform various distance judgement tasks. Finally, they will be asked to complete a written test based on the subject material displayed in the VE.

5. CONCLUSION

As these studies are still in progress, it is naturally difficult to predict the outcomes. Obviously we would predict that the results will point to the spatial method in VR being a good teaching tool; equally obviously, if we knew the answers the study would be unnecessary.

But be that as it may, we do expect to find that learning is more enjoyable in VR, due in part to the novelty of the medium, but also because it provides a more active way of interacting with the data to be learned but without the mental effort required for memorization. The design of the study does not allow for the pinpointing of a reason for the possible difference in enjoyment, but this is not crucial to the aims of the study. If VR-based learning is more enjoyable that conventional learning purely because of the novelty value, it does not detract from the fact that it *is* still more enjoyable. This would only be of import if spatial VR-based learning is used frequently enough for the novelty value to wear off over time.

We also expect that accuracy of learning and of cognitive mapping will be better with an HMD than on desktop VR, mostly because of the more natural movement that it affords. However, VR equipment is expensive, and teaching using this spatial method may be restricted to exhibitions and shows if it is not equally effective using desktop VR, which is far cheaper and could be incorporated into school activities.

With regard to map type, we suspect that an accurate, cartographic map will better support wayfinding (although some literature suggests that providing a map may hinder wayfinding [5], and that no map may be best of all), and that an impressionistic sketch map will help most with building up a mental idea of the data represented by the environment.

We also expect that the higher the sense of presence felt by the participant, the more accurately they will learn the environment (as they then remember the environment as a real place, somewhere that they can revisit in their minds).

Finally, although everyone has different levels of spatial abilities, we believe that the minimum level necessary to be able to make use of the spatial method is the same level that is necessary to be able to perform normal daily tasks.

In summary, then, we feel that by converting data relationships to spatial relationships, and using a VE to represent these spatial relationships, participants will be able to use their innate spatial abilities to understand and remember the data, and have a more enjoyable learning experience.

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