THE ROLE OF VISUAL ANALOGY IN INFORMATION VISUALISATION

By

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ABSTRACT

This thesis is inspired by the growing domain of information visualisation, and the potentially open-ended choice of visual representations which can be used to represent any given abstract concept. Such a potentially unlimited choice means that the question of choosing an appropriate visual form is not insubstantial. This thesis therefore attempts to explore how to usefully inform such a choice through the concept of visual analogy. To this end a series of multidimensional icons are developed which differ in terms of level of analogy for a given concept. The practical studies outlined then set out first to confirm this difference in practical terms and then explore the implications of using different levels of explicit visual analogy in tasks appropriate to the use of multidimensional icons.

The results reveal that a continuum of 'degree' of analogy can be practically established which increasingly constrains the interpretation users assign to representations as the level of analogy increases. Despite the fact that reading the meaning of representations employing visual analogy involves a tangible effort, the constraint which analogy puts on the interpretation of possible meanings is demonstrated to lead to advantages against more traditional ways of representing the same information, a fact which is not immediately appreciated by users. Moreover it was found that this constraining of interpretation which visual analogy provides can lead to the adoption of widely different task strategies.

In conclusion it is proposed that explicitly incorporating analogy can be beneficially used to support users in understanding the meaning of visualisations, and is therefore a potentially beneficial way of deciding on appropriate visual forms. However this benefit will often be tempered by the idiosyncrasies of the particular representation chosen as well as the task for which the representations are being used.

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Chapter 1 – INTRODUCTION

"*The power of the unaided mind is highly overrated. Without external aids, memory, thought and reasoning are all constrained....The real powers come from devising external aids that enhance cognitive abilities*." (Norman, 1993; p.43)

Card et al,. (1999) who bring attention to the above quote, state that graphical inventions are an important class of such aids, which can amplify cognition, quoting the oft used adage "A picture is worth ten thousand words". A variety of other claims exist which also intuitively lend support to the use of visualisation. For example, it has been stated therefore that 50% of neurones in the brain are associated with the visual system (McCormick et al., 1987) and that 60% of human mental processing power is devoted to visual processing (Latour, 1986). The importance that visual thinking has played in precipitating cognitive insight is also frequently cited in anecdotes. One such example is that of Friedrich Kekule's insight into the structure of the Benzene molecule which reportedly came through a dream of a snake eating its own tail (Kaiser, 1991). On a slightly less elevated level, metaphors are also used in everyday phrases in the English language to indicate understanding such as "to shed light on a situation" and "I See" (Erickson, 1991).

In the light of such claims, it is not surprising that the use of graphic aids to enhance cognitive abilities is not new (Tufte, 1983). An important development over the last couple of decades however has been the exponential increase in power of information technology which has been witness to dramatically increased graphical rendering capabilities, together with a marked decrease in the price of such technology. The combination of these factors now means that the ability to produce an almost unlimited range of complex graphical representations is widely available. Such representations can be used to portray real data, potentially allowing previously hidden aspects of this data to be revealed and in so doing acting as a powerful external aid to enhance native cognitive abilities (Card et al., 1999).

1.1 Information Visualisation

Information visualisation attempts to apply the benefits of visual representation to the understanding and manipulation of abstract information – meaning information which has no pre-existing physical basis to use as a basis for deciding how it should be represented. Information visualisation is a complex area embracing many fields. Examples range from multivariate databases (Ebert et al., 1997; Olson et al., 1993; Becker, 1997; Van Teylingen, 1997) such as "Information Visualizer" (Card et al., 1991), 'Tennis Viewer: a browser for competition trees' (Jin & Banks, 1997), computer maintenance programs (Fyock, 1997), as well as business visualisation spreadsheets (Huai-Hsin et al., 1997; Wright, 1997; Thomsen, 1990).

This thesis will investigate information visualisation from the standpoint of the meaning of the information being represented. Much visualisation research has concentrated on the syntactical side of matters and how this can 'amplify' cognition (Card et al., 1991; Tufte, 1983; Bertin, 1983), whereas the role of the meaning of the data featuring in the visualisation has received less attention. It will therefore be investigated here whether the underlying meaning of the information being represented can be used to help inform the question of which form to use.

In attempting to bring together the issues of the meaning of the data being represented and the visual instantiation of this meaning, this thesis will centre around the use of visual analogy. It will be described how analogy is an element the use of which has been well documented in other cognitive areas such as linguistic comprehension, learning and problem solving and more recently in Cartesian graphs. There is much scope however for explicit use of visual analogy to be capitalised upon given the almost unlimited range of rich, alternative and customisable representations which can now be produced.

1.2 Visual Analogy

The general concept of analogy has been held by many authors to be very important to cognitive functioning in a wide range of situations. These include problem solving (Gick & Holyoak, 1980; Gentner & Gentner 1980), communication (Lakoff & Johnson 1980, Richards 1965) as well as much of the thought underlying this communication (Gentner 1983, Bassok 1998). An important aspect of analogy is that it provides a way of dealing with novel situations through the structured application of previously acquired knowledge (Gentner & Markman 1997, Holyoak & Thagard, 1997). The structure of the new area can then be communicated by relating to the structure of the old, already understood area.

This is a concept which has already been appreciated in the visual domain. Gattis & Holyoak (1996) therefore noted that participants were better able to understand higher order concepts when the visual representation of this (a graph) was mapped in analogical manner such that the slope mapping constraint was honoured (i.e. more accurate judgements on the rate of change could be made when this was based on the visual mapping steeper = faster). Gattis (2001) has also described out a set of constructs which combine to make visual analogy – these concern relations to real world objects (iconicity), associations based on experience, direction of mapping and similarity of structure between the object being represented and that doing the representing.

The specific issue of visual analogy is therefore a useful way of explicitly heeding what is necessary to make an analogy and potentially harness the benefits which analogy has been proven to yield in other areas. Its use is nevertheless still under appreciated as a means of deciding on the forms representations should take. Card et al., (1999) for example state that mapping in a good visual structure should preserve the data, but are not more specific as to how abstract relationships without form can be represented. Spence (2001) also alludes to the importance and use of semantics when representing information using multidimensional icons but does not give details as to how the semantics of the domain being represented should be accounted for when no real world object exists as a convenient basis to conduct such mapping.

The position taken in this thesis will be that when appropriately employed, analogy can beneficially be used as a way of deciding how to represent abstract and formless concepts for a range of tasks in which information visualisation can be used. It will focus on the use of visual analogy in multidimensional icons as a way of demonstrating this. These are described in the following section.

1.3 Multidimensional Icons

Multidimensional icons are a form of information visualisation which uses objects to represent sets of information consisting of numerous related variables. Each of these singular variables is then mapped to aspects of the object. An important aspect of such mapping however is that there are no established reading conventions to provide rules as to how this mapping should be configured. One of the most well known multidimensional icons is the face (Chernoff, 1973) of which the various features (e.g. eyes, nose and mouth) are used to represent aspects of financial data (e.g. Working Capital, Net Worth, Sales). Faces have been used by a number of different authors in tasks where overall classifications of the data featured, such as judging whether a company is about to go bankrupt (shown by a sad face) was required. In this case the task of judging many variables was transformed into looking for facial expressions. Ware (2000) also describes how a graphical representation of a storage tank can be used to represent data relating to a storage vessel in a chemical plant. Capacity can therefore be represented by size of the tank, liquid temperature by colour of the liquid, chemical composition by texture of the liquid in addition to a number of other variables. Ware states that the advantages of such an object display is that it can reduce accidental misreadings of the data values and that mistakes are less likely as components act as their own descriptive icons.

A problem of using multidimensional icons however is deciding on the form that is used. As they do not rely on established graphical conventions, a wide range of options is available, potentially meaning that a sub-optimal representation could be used. Spence states that one of the factors contributing to the fact that Spence & Parr (1991) were able to demonstrate the benefits of multidimensional icons is that the icons they featured (a house) possessed a semantic relationship to the task featured (choosing housing data). Ware (2000) also cites advantages of using such icons where a clear mapping can be established through relations with a real world physical counterpart. In cases where no real world object is available however, which is often the case when representing abstract data, such an object is not available. In this case, a basis is needed to decide on a suitable representation. The argument mentioned by Spence that semantic relations are crucial, fits well to the concept of using visual analogy as a means of deciding upon which representation to use. Objects which possess similar semantic relations to the dataset described can therefore be used as a way to maintain these semantic relations and still make them explicit. It is argued in this thesis however that the concept of defining what semantic relations constitute needs to be thorough.

The use of analogy in multidimensional icons will therefore be investigated on this basis. It will be argued that the appropriate use of analogy is a potentially beneficial way of deciding how to represent information. Given the job that multidimensional icons perform, namely using explicit visual entities to represent abstract data which does not necessarily have any iconic relation to the entity used, this can be seen to be a common task in information visualisation, as a view in any compendium of information visualisation examples will show (e.g. Spence 2001, Ware 2001). A focus on multidimensional icons and visual analogy is therefore not insignificant to an investigation in the emerging field of information visualisation.

1.4 Thesis Aims & Structure

This thesis aims to investigate the effects of visual analogy in structuring multidimensional icons. In order to do this, the thesis will attempt to take a relatively holistic approach focussing on what might be helpful about using analogy, what the negative implications of thinking by analogy might be as well as how users react to using analogical representations both before and after actually gaining experience with such representations. The aim then is to gain an idea of the costs and benefits of using analogy in terms of performance, as well as factors such as user impression which are also likely to influence the use and uptake of novel analogical forms of information visualisation.

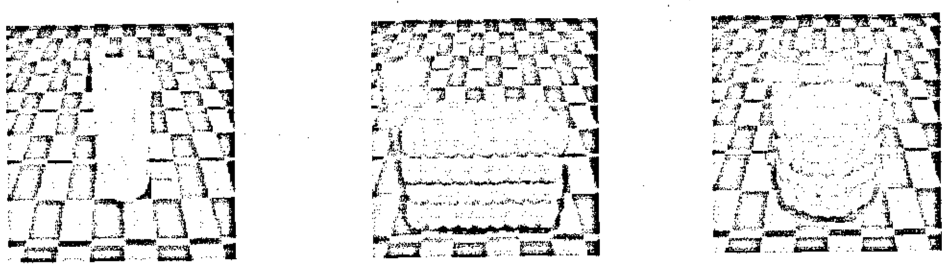
The overall research questions which the thesis will concern itself with are – If and how analogy works when representing quantitative information? How this can help in what Card et al. (1999), describe as amplifying cognition? In addition, how can answers to these questions help inform the choice of visual analogy? These broad questions will be answered in the framework of the following thesis structure.

Chapter 2 will provide a literature review of the area, describing in more detail exactly what information visualisation and multidimensional icons are as well as providing examples of techniques and applications. Issues relevant to the use of analogy, such as mapping are also introduced together with a summary of techniques used to date to decide on the form and mapping of analogical representations.

Having given an overview of the applied aspect of information visualisation, the psychological side will then be reviewed. This will include in particular, the concept of analogy and how a continuum of analogy ranging from 'low' to 'high' can be derived - a foundation of the experimental work in the thesis. The focus on analogy will then be complemented by other psychological theories in order to give a more general background into how visualisation is believed to work. The literature review will conclude with a review of how effective the concept of visualising information has actually proven to be in the literature. The importance of the interaction between users, tasks and the situation will then be discussed together with the validity of 'findings' from any one experimental study to this broad and diverse area.

Chapter 3 will discuss the methodology employed in this thesis, laying out potential options available and explaining the current methodology given the maturity of information visualisation as a field and the questions being asked in this thesis.

The first study presented in ***Chapter 4*** will then introduce the concept used in all experiments in the thesis, namely that of financial shares. It will then demonstrate how three different representation types (see Figure 1-1) can represent these variables and make explicit the relationships between them to various degrees.



CYLINDER
Representation 1

WALL
Representation 2

CONTAINER
Representation 3

Figure 1-1: The three representation types to be used in the thesis

It will be hypothesised that the explicit representation of the relationships will constrain the choices users make of which pictorial variables map naturally to the share variables introduced. This experiment will also serve as a method of deciding which concept variables should be mapped to which physical variables in future experiments.

The experiments described in ***Chapter 5*** will attempt to gain a more complete idea of how analogy works in the context of multidimensional icons, by demonstrating the implications of thinking by analogy in terms of the cognitive cost involved. The time taken to sort representations by their meaning will therefore be compared against the time taken to sort them by pictorial or verbal descriptions of their appearance. The implications of the cost of using representations relying on visual analogy will then be considered against any benefits that using visual analogy might bring.

The experiment described in ***Chapter 6*** will then attempt to take a look at these benefits by comparing traditional bar graph and tabular representations, which at first glance appear to provide more support for the categorisation task featured. The 'high' analogy representation will therefore be used as a means of comparison, in order to gain a better idea of what the helpful aspects of analogy might be. As well as the standard objective measures, subjective measures will also be taken in order to gain an insight into motivational factors which may influence the uptake and use of analogical representations.

Chapter 7 will then present a study investigating the role of analogy level in a categorisation task. Two representation types ('High' and 'Medium' analogy) which appear similar will be used in order to establish if analogy is a meaningful and helpful construct in the context of visual representations. The study presented here will also attempt to take a more precise look at exactly how analogical representations might be helpful, not just in terms of standard objective measures, but also in terms of different strategies which the different representation types encourage.

A second and similar study is then presented in ***Chapter 8*** which extends the findings of the previous study by comparing representations with greater analogy difference ('High' and 'Low analogy). This experiment will also extend the findings of the experiment described in the previous chapter by taking more comprehensive measures of the various task parameters which were found to be of interest previously. A greater insight in to the roles of external cognition and any potential systematic biases which the representations may give rise to will therefore be sought.

The discussion in ***Chapter 9*** will then summarise the findings and discuss their contribution to our understanding of visual analogy in multidimensional icons –a class of information visualisation which has wide-ranging implications for information visualisation as a whole. A discussion of the research strategy will also feature together with a design implications section to summarise the findings relevant to choosing and working with multidimensional icons.

Chapter 2 - LITERATURE REVIEW

This literature review will now provide a background to the areas relevant to the topic of visual analogy in information visualisation. Broadly speaking, the chapter will begin with a description of information visualisation and what it consists of, before considering the question of analogy, and how this features at a psychological level. Finally, a psychological context to information visualisation use will be provided.

2.1 What is Information Visualisation?

Card, MacKinlay & Schneiderman (1999) define information representation as

> "The use of computer-supported, interactive, visual representations of abstract data to amplify cognition."

This is a useful definition as it specifically states the goal (to amplify cognition), the pre-requisites (computer-supported, interactive and visual) and the medium being worked with (abstract data). It is also important however to define exactly what constitutes an 'information visualization', in particular to distinguish them from other types of visual representation that do not fall under the banner of ' information visualisations'.

Winn (1987) makes a distinction by describing a continuum along which written and spoken language sit at one end and realistic pictures at the other. The rationale for this is that pictures resemble what they stand for while words are arbitrary and conventional. Winn describes charts, graphs and diagrams as lying in the middle of this continuum as they inherit the attribute of abstraction from words but like pictures exploit spatial layout in a meaningful way. In this sense so too does information visualisation as it both employs abstraction –therefore distinguishing itself from pictures- and exploits spatial layout- therefore distinguishing itself from written and spoken language.

In terms of making a distinction between Information Visualisation and charts, graphs and diagrams - Diagrams can be distinguished in terms of both function and complexity. The function of diagrams is to describe whole processes and structures often at levels of great complexity. While information visualisations are also potentially complex, a key difference is that information visualisations do not need to represent whole processes. In addition diagrams do not by definition need to represent abstract data or be computer supported or interactive.

The two other types of graphical representations Winn mentions, charts and graphs, can be defined by the fact that their purpose is to illustrate simple relationships between variables. Charts do this with categorical variables through the use of sequence often making use of the tabular organisation of column and row headings while graphs show relationships among variables at least one of which is continuous. It is hard however to draw a firm line between research on these different types of representation as aspects of them can all be relevant to information depending on the form and purpose. Findings from different studies in different areas therefore need to be considered on their own merits.

In terms of visualisations there are two other types which may be confused with information visualisation, these being scientific and data visualisation. They do not form a focus of this thesis however and are described below:

Scientific Visualisation

The additional word "abstract" is important in making a distinction between information visualisation and scientific visualisation, as the former provides a physical form to data which does not in reality have one (e.g. profit or time). As such information visualisation is distinctive from 'Scientific Visualisation' where the collective data points being visualised usually already have a physical relationship between one another such as is the case for example with biological data (Chi et al., 2000) or geographical data (Kreuseler, 2000). In each case the physical form from which the data originates is displayed and the data values mapped to a version of this physical framework.

Data Visualisation

Data visualisation is a less specific description than information visualisation (the terms often being used interchangeably) and can justifiably describe all types of visualisation – data being at the heart of all these (Erickson, 1993). The term is normally used however to describe data sets which are smaller and less specialised than those encountered in scientific visualisation. Data visualisation is also sometimes distinguished from information visualisation in that the organisational element which categorises information visualisation is less developed - data being information at a less developed stage of processing.

An integral part of information visualisation is that the visualisation is interactive and computer-supported. The position taken in this thesis is that an understanding of the field can and indeed must (if prior research is to be effectively used) take into account psychological principles and basic visualisation techniques which do not require interaction and which do not need to be computer mediated. Hence the focus is on a sub-section of information visualisation, namely the representation form which can subsequently be made computer supported and interactive.

2.1.1 A History of Information Visualisation

Although the term 'visualisation' is a fairly recent one, coined after the arrival of information technology. Aspects of the process it encompasses have been in use for a relatively long time. The first consistent use of abstract, non-representational pictures to show numbers first made an appearance around 1750-1800. This was long after the first geographic maps had been created, the earliest known ones pre-dating the first statistical graphs by approximately 5000 years. Perhaps surprisingly, however, this was long after the invention of Cartesian co-ordinates, logarithms, calculus and the basis of probability theory. One argument as to why this is so is due to the diversity of skills: visual-artistic, empirical-statistical and mathematical which are necessary to create them (Tufte, 1983).

Two of the men credited with being the inventors of modern graphical design are the Swiss-German scientist J.H. Lambert (1728-1777), and William Playfair (1759-1823) an English political economist. Lambert was the earlier of the two and has to his credit a number of the earliest examples of abstract numerical representations, showing for example the variation in speed with depth of soil temperature changes, and the evaporation of water with temperature. Playfair on the other hand is accredited with broadening the repertoire of early graphical formats, being the first to make use of the bar graph and the pie chart.

The specific term "Information visualisation" as it is understood today, was first used in 1989 (Robertson, Card & Mackinlay, 1991) and arose in conjunction with the more powerful computer graphics capabilities which were emerging. These allowed for a new breed of graphical user interface to be designed opening doors for a number of new applications including in particular visual, multivariate databases (Ebert et al., 1997; Olson et al., 1993; Becker, 1997; Van Teylingen, 1997) such as "Information Visualizer" (Card et al., 1991) which used techniques such as distortion and animation to selectively interact with, highlight and de-emphasize certain aspects of the data being displayed. Since then many more such applications and visualisation methods have been developed in order to accomplish a wide range of tasks. These have included such examples as 'Tennis Viewer: a browser for competition trees' (Jin & Banks, 1997), computer maintenance programs (Fyock, 1997), as well as business visualisation spreadsheets (Huai-Hsin et al., 1997; Wright, 1997; Thomsen, 1990). A number of journal series dedicated to information visualisation have also been published (*IEEE Spectrum*, 1995; *IEEE Computer Graphics and Applications*, 1997) together with a growing number of reference text books (Card et al., 1999; Spence 2000; Ware, 2000) and conference symposiums.

As technology continues to accelerate, the use of information visualisation techniques and applications is anticipated to become available to an increasing number of people, particularly via the internet (Rohrer & Swing, 1997; Munzner & Burchard, 1995). The history of visualisation and in particular information visualisation is therefore very much ongoing.

2.1. Information Visualisation Techniques

Having described what is meant by information visualisation, a number of techniques will be described which illustrate how information visualisation works on a technical level as well as how visualisations can be manipulated to become more effective for a given task. These mechanisms have been described in different manners by different authors – Bertin (1983) for example, talks of the three building blocks of visualisation being spatial substrate, marks and the graphical properties of these marks. Card et al., (1999) has then expanded on these and along with Spence (2001) has been more specific with regard to the manipulations both before and after representation. This overview will attempt a concise synthesis of these views providing at the same time, examples where use of the mechanisms described can be clearly seen. The overview will roughly follow the steps involved in choosing, representing and using a visualisation. First the information to be represented must be selected and a decision made on what to show and what not to show. Secondly, the selected information must be represented using a variety of potential techniques. Once this representation has been established, there are then a number of alternate ways in which it can be presented. Finally, once a particular way of presenting a visualisation has been chosen, the visualisation can then be interactively explored in a number of ways. This section will now give an overview of the various options and methods at all of these steps.

2.1.2 Selection

One of the key mechanisms of information visualisation is selection (Spence 1999). This refers to the process of making some aspects of information highly visible, while suppressing other aspects of information judged irrelevant to the task at hand. This is a stage which often occurs before the information is presented to the user and is closely tied to the purpose for which a visualisation is created. An early example of the efficient use of selection was a graph created by Florence Nightingale, showing the rate of deaths in army hospitals during the Crimean war in the mid 1850's.

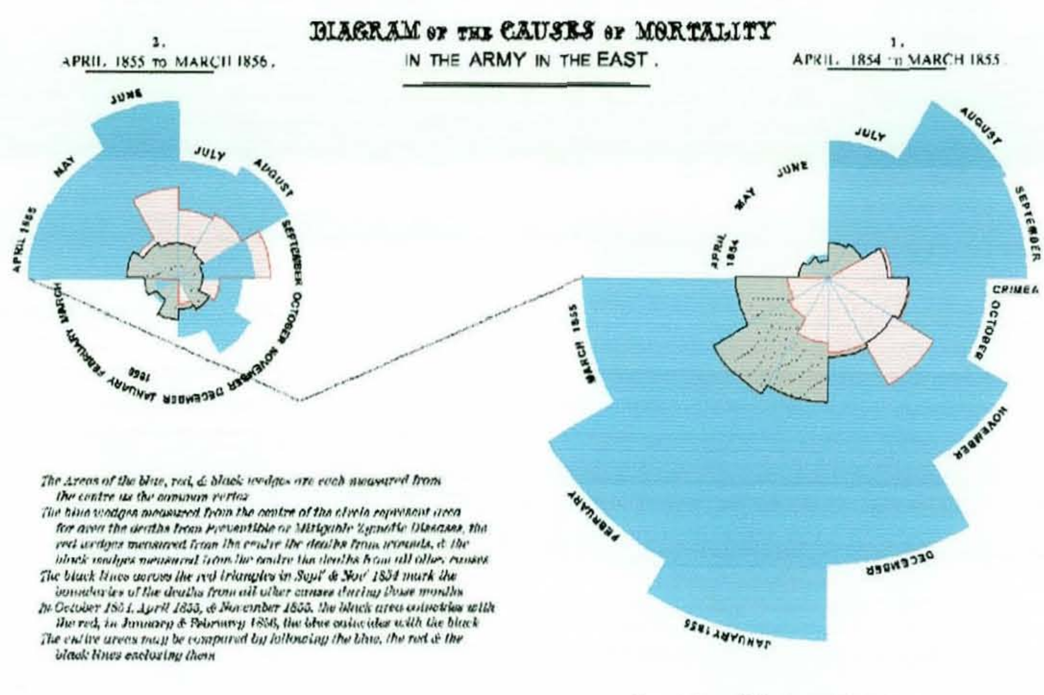


Figure 2-1 - Early graph created by Florence Nightingale (Source: Small, 1999)

Here deaths have been split into three classes, blue wedges (to diseases which were preventable through improved hygiene), red wedges (to deaths from wounds) and dark grey (from all other causes). The two graphs above also lead on from one another, the right beginning at April 1854 and progressing clockwise to March 1855, and the left (following the dark line) beginning where the previous graph ends at April 1855 and continuing to March 1856. It is possible to see that the incidence of preventable deaths increased dramatically in July and August 1854 far exceeding the level of deaths from wounds, and then decreased gradually from January 1855. By September 1855 it can be seen that deaths from preventable diseases was lower than rate of deaths from wounds.

Selection has been used in a number of instances in the creation of this representation. Firstly, there are just three classes of death, suppressing information judged as irrelevant (e.g. a full description of the cause of death) to the point being made. Similarly, certain time periods only are being shown, presumably years surrounding and encompassing the duration of the war. There are also a host of other connected variables which could be shown but have not been, as they have been judged irrelevant to the point being made. These include for example, the number of medical staff, morale, and level of available medicine to name but a few. Florence Nightingale was successful in persuading the Sanitary Commission to undertake improvements in hospital conditions in the Crimea, and through the efficient use of selection, was clearly able to show how these improvements were successful. It should be noted however, that precisely this use of selection led to criticisms by contemporary critics that the diagrams did not show the true cause of the improvements (Small, 1999)

2.1.1. Representation

Once a decision has been made about which variables are to be selected for representation, a decision then has to be made as to how these variables should be represented. Representation elements can be usefully divided into the categories of marks (Card, 1999) which are the visible elements of a visualisation, and spatiality (Spence, 2001) which refers to the organisation of these elements within space. Marks in space can then take on values that have perceptual connotations such as patterns and connectivity as well as semantic connotations where knowledge or understanding of a particular concept are specifically invoked through the representation portraying a real world object.

Marks

These are the visible elements of a representation and are according to Bertin a first 'fundamental building block' of visualisation. They can be divided into four types (Card et al., 1999):

- Points (0D or zero dimensional)
- Lines (1D)
- *Areas (2D) – Includes surfaces of three dimensional objects*
- Volumes (3D)

Marks can then be given graphical properties which are a second fundamental building block of visualisation. Bertin (1983) describes these as 'Retinal properties' as the eye is sensitive to them independent of position. He described six, while these have been added to by MacEachren (1995) and Healey et al. (1995).

Retinal Property	Origin
Size Orientation Gray Scale Colour Texture Shape	(Proposed by Bertin, 1983)
Crispness Resolution Transparency Arrangement Colour Value Colour Hue Colour Saturation	(Proposed by MacEachren, 1995)
Number Line Orientation Length Width Size Curvature Terminators Intersection Closure Colour Intensity Flicker Direction of Motion Binocular Lustre Stereoscopic Depth 3D Depth Cues Lighting Direction	(Proposed by Healey, Booth & Enns, 1995)

Table 2-1 – Summary of Retinal Properties

Spatiality

This refers to the use of space itself as an organisational mechanism into which Marks can be placed. This is the third of the three fundamental building blocks described by Bertin (1983). Card (1999) outlines four types of axes against which space can be divided and quantified. These are:

- Unstructured Axis (no axis)
- Nominal Axis (a region is divided into sub-regions)
- Ordinal axis (the ordering of these sub-regions is meaningful)
- Quantitative Axis (each region has a metric which can be categorised into ratio or interval increments)

When configured in certain ways, spatiality can be used to produce effects which take on additional weight, and which can be used as an additional means of information representation. Patterns and connectivity are two important examples of this (Spence, 2001). Patterns have been demonstrated as being a useful method to represent normality and abnormality in the context of plant process control (Goettl, Wickens & Kramer, 1991) as well as a method for quality control in the manufacture of mass-produced electrical equipment (Spence, 2001). Connectivity, or the highlighting of a connection between two or more elements in a representation is also a commonly used technique, and has found much use in the field of telecommunications – specifically in the representation of telephone, email and internet connections, as well as less obvious applications such as the detection of fraud (Westphal & Blaxton, 1998)

Cone trees illustrate how connectivity can be used to illustrate which objects in a database are related to each other (Robertson, 1991). These organise information on an explicitly hierarchical basis. The most important object of interest is represented as a root node at the top of a tree, while inferior nodes are shown as subsets of the root node. Each subsequent node then itself becomes a root node and the process continues. Visually, the size of the resulting cone decreases as one moves further down the hierarchy. Originals produced at Xerox Parc enabled rotation for improved examination. It was found that this smooth rotation enabled the viewer's cognitive model of the structure to be more effectively maintained.

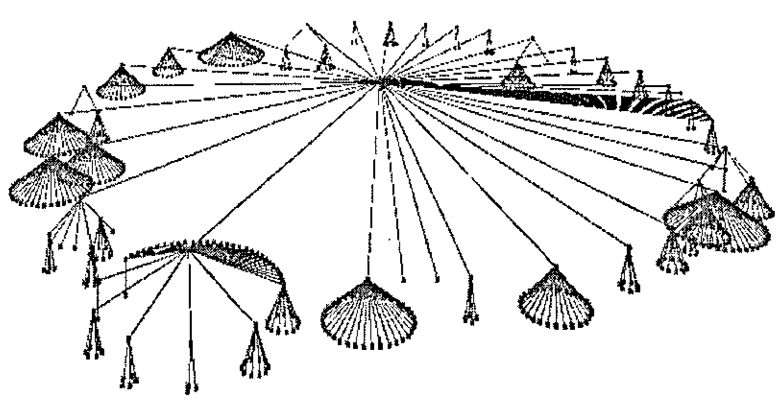


Figure 2-2: Cone Trees (Courtesy of Benford S, in Young, 1996)

The cone tree visualisation is useful for a number of reasons. Firstly it explicitly represents the relationships inherent within the dataset shown. The use of 3D space also allows a large number of these to be displayed in coherent way. The form of the design together with the smooth rotation which was later included also means that navigation is possible while at the same time maintaining a view of the other documents displayed.

2.1.2. Presentation

Once a particular representation has been decided upon, this must then be presented to the user in some manner. This can be achieved in a number of ways, which are of varying use depending on the particular representation being used and the task it is being used for. A commonly encountered problem when using information visualisation is that the amount of information which can be viewed at any one time is limited both by the screen space and resolution as well as the perceptual apparatus of the user. A number of methods have been developed to deal with this problem, some of which overlap or are used together in particular applications. These include: Scrolling, Panning & Zooming, Suppression, Distortion, and Riffling.

Scrolling

Scrolling is one of the most commonly used methods of focussing on a particular sub-set of information at any one time. This involves moving a window of a given size and resolution up and down a particular representation so that certain parts of the information can be seen, and others cannot. As Spence (1991) points out there are a number of problems with this technique, which revolve around the fact that it is difficult to gain an idea of the context of the whole document from such a window.

Panning & Zooming

A method which attempts to address the context problem directly but uses a method similar to scrolling is that of Panning & Zooming. Scrolling can in fact can be considered a form of panning restricted to a linear dimension. The enhancements which panning and zooming bring as a combined technique are that they enable movement of a view window to be made freely in three dimensions. Panning therefore enables free movement in two dimensions while zooming allows increasing (or decreasing) magnification of a particular area of interest. This is important as it allows an overall idea of context to be gained before 'zooming in' can be carried out to examine details.

Suppression

Suppression refers to the method of hiding certain aspects of information within a given display space, so that those which remain become more salient. Mitta (1990) demonstrates this in the context of an engineering diagram and shows how hiding pieces of a solenoid which are irrelevant to the task at hand can drastically simplify an assembly and de-assembly task. Colby & Scholes (1991) also demonstrate the principle in the 'z-thru mapping technique', showing how a map can be covered by a number of information layers, each associated with some feature of the area such as Crime statistics, air corridors or traffic density. The user can then attenuate the transparency of each of these layers according to their interest (Spence, 2001).

Distortion

Distortion is a useful technique as it allows for a combination of both the detail of a particular area of interest as well as the context in which it exists to be displayed at one time. Examples of visualisations which make explicit use of this approach include the Bi-focal display (Spence & Apperley, 1982) and the Perspective Wall (MacKinlay et al., 1991). The perspective wall allows the focus of attention to be displayed in the middle of the screen, while context is provided at the edges. It can therefore be seen that there are many items on the wall to the left of the main focus, and relatively few to the right. At the same time however the view of the main focus remains unimpeded.

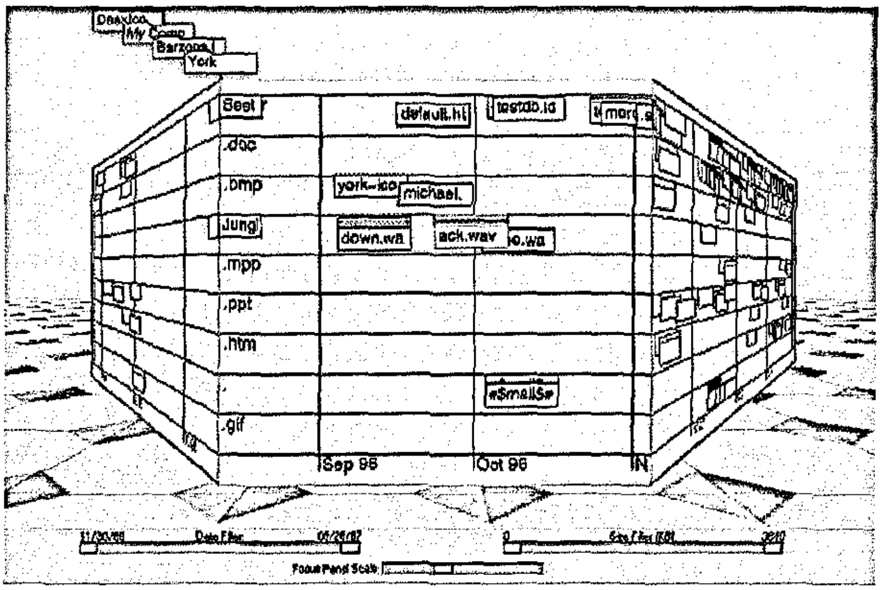


Figure 2-3 - The Perspective Wall (Source: Inxight Software)

The perspective wall is based on an X-dimension distortion, however this can also be applied in the Y-dimension as has been demonstrated in the Document Lens application (Robertson & Mackinlay, 1993)

Riffling

Another technique which can be used to cope with the presentation of large amounts of information within a small screen space is that of riffling (or rapid serial presentation). This allows many screens of information to rapidly shown to the user over a set period of time in a similar manner to flicking through the pages of a book. A broad idea of the content can then be gained, although particular screens may then need to be re-visited to assimilate the information shown there in more detail. This technique has been demonstrated by Lam & Spence (1997) in the context of a video-on demand presentation to support the browsing of video posters. Wittenberg et al. (1998) have also to present goods and service to potential customers in a sequential manner.

2.1.3 Interactive Exploration

Once information has been displayed in a certain way with the most important areas of interest visible, an important and valuable aspect of information visualisation is that it allows for this information to be actively explored. This entails the re-arrangement of the data or the engagement of a process which allows a selection of new information to be brought into a given visualisation.

Rearrangement can be performed manually or automatically – and is useful in situations where a vague idea only is held of the attributes in question. This allows particular queries to be reformed once more knowledge of a particular situation has been gained.

Table Lens

The Table Lens (Rao & Card, 1994) demonstrates how interaction can take place in an information visualisation context based on the concept of rearrangement. The data shown is divided into columns. All of the information shown can be ordered according to whatever column title is of interest. In this example, they have been ordered by sex, event and year. The information could equally well be viewed by country or overall result.

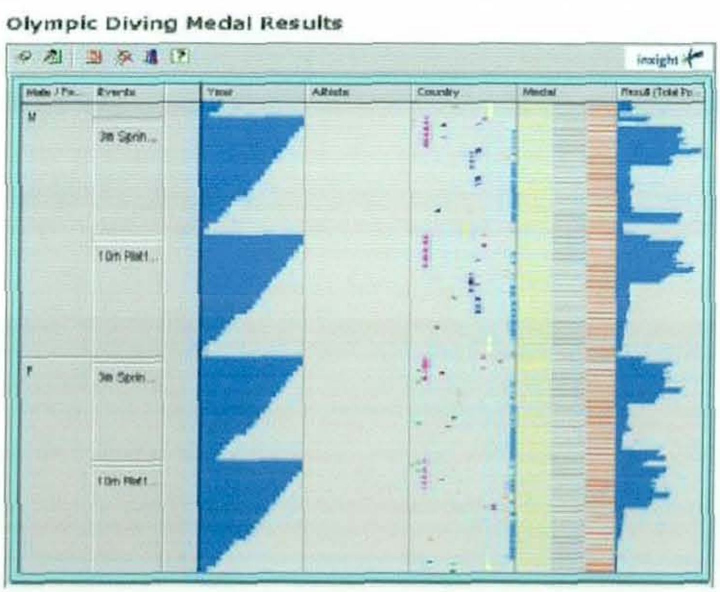


Figure 2-4: The Table Lens (Source: Kolach & Weinstein 2001)

Spence (2001) describes how the data can be interacted with in a very simple manner, by drawing a line or tick with the mouse. This allows a more detailed histogram to be obtained of the information outlined. This method of information visualisation is potentially effective as it allows a large amount of data to be displayed at one time. From the large amount of information displayed, it is then easy to make a decision on which aspects should be focussed on in more detail.

This ability allows users to formulate a problem concurrently with solving it (Spence 2001). This fact forms the basis of dynamic queries (Williamson & Shneiderman, 1992) which allows a 'most suitable' or small group of 'most suitable' candidates to be selected out of a larger collection. Based on the concept of dynamic queries then, the task of searching for a house from a collection of displayed houses, for example, can be eased by allowing the range of houses shown to be increased or decreased with an immediate response time by means of sliders relating to price, no. of bedrooms, garden size or other variables. This allows many 'what if' scenarios to be formulated and immediately answered in real time.

2.1.4 Summary

In this section an attempt has been made to illustrate the basic stages and techniques which are involved in creating and using information visualisations in order to demonstrate the possibilities which exist. Some examples have also been included which demonstrate certain aspects of these techniques. Of these, it is the presentation stage which will be focussed on in this thesis. This description has been technique driven rather than application driven as new applications are constantly being developed, and others become obscure over time through lack of development. The underlying principles of selection, representation, presentation and interactive exploration will not change however – hence in an attempt to avoid obsolescence, the technique led approach has been adopted.

2.2 Multidimensional Icons

Multidimensional Icons are a type of information visualisation that makes explicit use of the form of the visualisation chosen. They are manifested as objects of varying fidelity to the real world and represent multivariate data which is often quantitative in nature. They are of interest here as they explicitly embody the theme of investigation in this thesis, namely how analogy can play a pivotal role in information visualisation. A pre-supposition of this thesis is that the act of representing real world objects renders multidimensional icons capable of harnessing analogical processes which can then potentially be used in any application in which they are employed. In terms of the information framework employed above, a focus on multidimensional icons focuses on the second stage, namely the representation of the data. It is therefore assumed that the data to be used has already been chosen, and that presentation and interaction are stages that can be applied to the representation at a later point.

2.2.1 A definition

The term 'multidimensional icon' can be found in more than one context and so there is some need for clarification. The term has been used to describe icons such as those from an operating system desktop when arranged on different sides of a cube (Henry & Hudson, 1991). These icons were multidimensional in the sense that each side represented a different view of the same object. If the object (for example a computer program) was viewed from the text side, then it would be associated with the application (a word program) that operates on a text file. If it was viewed from its 'program' side then it would show a different icon (this time associated with a code compiler) that would be seen as a program code icon. Icons on each side of the cube therefore represented the different ways in which a particular object could be treated. This type of multidimensional icon will not be focussed on here.

The term 'multidimensional icon' as it will be used here was first mentioned by Spence & Parr (1991). Spence and Parr also use the term 'Portrayal Icon', while previous work on the same phenomena described them as 'multidimensional graphics'. (Moriarty, 1979; Stock & Watson, 1984) The most recent description of the phenomena (Spence 2001) also used the term 'multidimensional icon' and hence it will be used here.

A need exists for defining exactly what is and what is not of relevance to a study of multidimensional icons. It could be argued that a Cartesian graph is another form of multidimensional icon, for example as it also represents multivariate information in graphic form. A working definition could therefore be that multidimensional icons represent multivariate data in a way that does not make use of established reading conventions. As such Multidimensional icons can be distinguished from charts and scatterplots although they may be employed for the same purpose. It also helps to establish aspects of interest in hybrid representations which employ a mixture of graphical representation and novel techniques. Anderson (1960) for example employs a 'glyph' method to represent multidimensional data, which uses a combination of Cartesian co-ordinates and circles and lines of varying diameter and orientation. The circles and lines aspect is of interest here, while the use of Cartesian co-ordinates is not. The absence of established conventions together with the fact that the designs will often not have been encountered before mean that the semantics of the form take on greater importance than otherwise.

'Multidimensional icons' as far as they are defined in the literature, are therefore a wide-ranging class of information visualisation which are of central importance to a study of the field as a whole.

2.2.2 Examples of Multidimensional icons

The range of multidimensional icons can vary widely. Examples documented in the literature range from abstract shapes to more semantically charged icons such as houses, castles, trees, faces and information cities.

Faces

Chernoff (1971, 1973) was the first to use faces to represent data. He achieved this through assigning different individual values of a different dataset to different values of the face. The quantity or level of this single variable will then have an impact on the form and expression shown by the face. Moriarty (1979) for example, in portraying the financial health of different companies mapped three aspects connected with Net Income (Working Capital, Sales, Net Worth) to mouth level, mouth length and mouth curvature respectively. The health of these variables then either caused the mouth to smile or look sad.

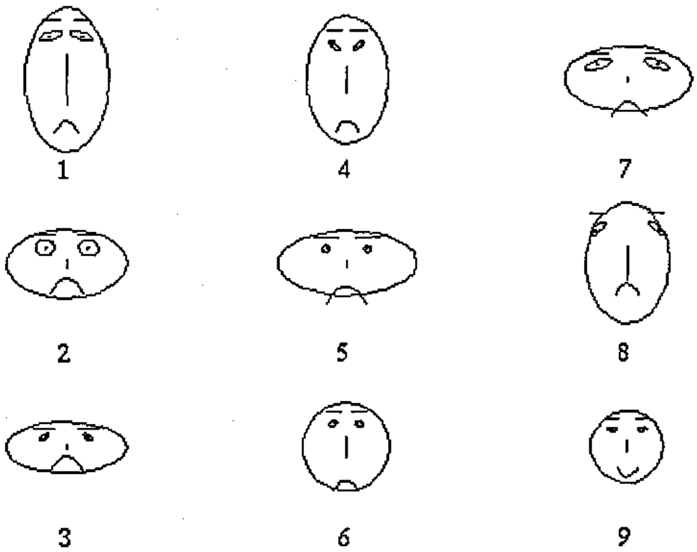


Figure 2-5 Examples of Chernoff Faces

In combination with other aspects of the face, it was hypothesised that such an arrangement would confer a number of advantages over traditional ways of representing data. Moriarty together with Jacob, Egeth & Bevan (1976) therefore claimed that the use of faces allows data to be perceived holistically, allowing perceptual recognition to replace the logical uptake of numbers leading to easier, faster and more accurate judgement. Moriarty (1979) also claims that the experience which humans gain with faces on a day-to-day level should facilitate the speed with which datasets can be categorised and at which trends in change across several different datasets can be spotted. Stock & Watson (1984) have also stated that faces can aid with combining large amounts of data under uncertainty, in part through allowing properties essential to judgement to be easily detected and by allowing this detection to be consistently applied. Faces have also been described as allowing improved encoding of data in memory (Chernoff, 1973; Jacob, Egeth & Bevan, 1976; Stock & Watson, 1984) by allowing the different variables present in the facial features to be parcelled under one associative structure such as “happy” or “surprised”. Stock & Watson (1984) also propose that faces should be easier to learn to use than tabular presentations.

By and large, empirical investigations of such claims have been able to show support for them. Jacob, Egeth & Bevan (1976) for example found that faces could be more accurately classified into a set of prototype classes than other abstract shapes. In the same study they also found that faces could be more effectively remembered as a whole than other multidimensional icons. In studies which probed the ability of novices and experts to spot companies on the brink of bankruptcy, Moriarty (1979) and Stock & Watson (1984) both found that this could be achieved more quickly using faces than when bar graphs and tables were used for both novices and experienced accountants. Moriarty (1979) also found that humans using the faces were able to outperform statistical prediction models at the same task. Concentrating on a less applied task, Wilkinson (1981) was also able to show that faces were a more effective representation format for spotting dissimilar datasets from a collection of many, than other types of multidimensional graphic.

A number of idiosyncratic issues arise when faces are used to represent data. Chernoff (1973) provides the example of using both the eyes and pupils to represent data elements. In some instances the value to which the size of the eyes is mapped may be too small to the extent that the pupils can no longer be seen regardless of the value they show. It was also noticed in this study that different aspects of the face were more or less salient to different individuals. Some people therefore reported only looking at the eyes, while others concentrated only on the shape of the head. Chernoff therefore raises the issue that the ability to use faces as a means of representing data may be heavily connected with an individual's past experience. Moriarty (1979) also observed a pronounced skewing of the results in his investigation relating to a pronounced mis-classification of certain datasets, attributing this to the particular facial configuration that these datasets gave rise to.

A further point raised in the context of faces, but potentially attributable to all multidimensional icons, is the concept of noise (Chernoff, 1973). It may therefore be the case that variables which are not important to the decision at hand, are nevertheless mapped to salient variables and cannot be easily ignored. It is therefore important to be mindful of these sorts of issues, either so that such effects can be avoided or utilised to enhance decision making where possible.

Object Graphs /Polygons

A key advantage of the object graph or polygon is that it is an easy way to represent 'normal' and 'abnormal states'. Normal states can therefore be represented by a perfect polygon, and abnormal states by a distortion of this regular shape. The object graph (Figure 2-6) is viewed as optimal for the presentation of separate variables which vary in terms of a limited number of dimensions, and accomplish this by collecting and integrating information in centralised displays that utilise geometric object formats (Goettl, Wickens & Kramer, 1991). The rationale for this novel type of display is that it allows greater "information extraction" as opposed to "data availability" (Woods, 1991) by providing support for the viewer as to what the data means and which aspects of the data are relevant for a particular decision to be made.

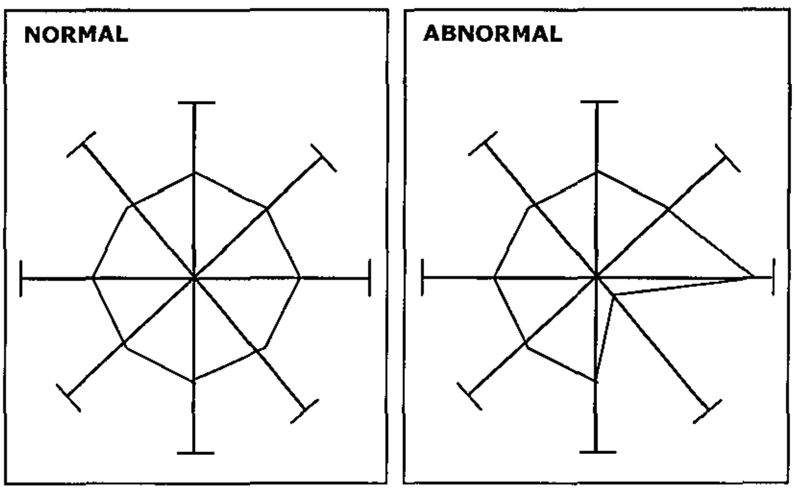


Figure 2-6: Object displays showing 'normal' (left) and 'abnormal' conditions (right)

A number of features of object displays have been explicitly pointed out in the literature. Barnett & Wickens (1988) have proposed that the key advantages of such representations are due to proximity compatibility and emergent features. The proximity compatibility theory asserts that information, which requires mental integration, should be physically integrated or proximate (such as in space or colour) to differing degrees according to the extent that multiple channels of information must be mentally integrated. Emergent features are described (Bennett & Flach, 1992; Bennett, Toms & Woods, 1993) as the additional perceptual properties that arise from the interactions among configural stimulus dimensions. An example of an emergent feature is the creation of a triangle on the joining of three straight lines. The effect is such that the triangle shape is the dominant feature perceived, and not the lines which comprise it.

A particular issue with regard to polygons is that when a certain profile of values appears, they can become extremely jagged in a way which can hinder information uptake. Such effects should be avoided where possible (Kleiner & Hartigan, 1981)

Metroglyphs
Anderson (1960) describes one of the earliest uses of multidimensional icons, having invented the 'metroglyph' to represent botanical information. Metroglyphs employ a circle together with rays emanating out from this circle at different angles. Each ray represents a different attribute of the dataset and In Anderson's example represented values which were either 'high', 'medium' or 'low'. Interestingly, these were also sometimes combined with traditional scatterplots, creating a hybrid graph / multidimensional icon representation. Anderson claimed that this representation possessed the advantage of more effectively allowing the inter-relationship between different variables to be shown, although no empirical data was presented.

Anderson raises a number of design issues which can occur when using such metroglyphs. After trying a number of different arrangements for the rays, it was found that the most effective was to have then facing in approximately the same direction to aid comparison. It was also found to be a good idea to make some "concessions to the eye" and represent the length of 'medium' rays so that they appear perceptually to fall mid-way between 'low' and 'high' values. If a mathematical approach was adopted so that the length was exactly halfway between 'low' and 'high' it was found that 'medium' was often confused with 'large'.

Castles & Trees
Kleiner & Hartigan (1981) developed two novel types of information visualisation – the tree and the castle. These were developed as a way of visualising multivariate data. A key advantage of these methods it was claimed is that they allow correlations between related variables to be saliently represented. Unlike faces which also have inherent correlations (e.g. width of eyebrows correlated to

width of eyes) it is not necessary to make a decision in advance as to what variables will be mapped to each aspect of the visualisation, as it would be with faces for example. Both trees and castles do rely on the fact however that all variables have comparable value scales. It is therefore not possible to represent qualitative data for example. The main purpose of these representation types is to highlight correlations and clusters and not to communicate semantic aspects of the data.

House icons

One type of icon, which was designed to expressly communicate semantic aspects of the data being represented, is the house icon (Spence & Parr, 1991). This was designed with a view to aiding decision making in a specific multi-attribute optimisation task. In this task, there were no clear-cut correct answers therefore. Rather the icons were designed to support the user in the need to find a 'best-fit' solution. The house icon was designed to represent housing information in a number of ways: The type of house was indicated by the icon shape (e.g. house or houseboat), while windows represented the number of bedrooms. If these were clear, it was an indication that the house was in good repair, and if they were black it showed that the house was in bad repair. A clock on the house showed the time required to reach a major railway station, while colour of the house represented the house price. The presence of a garden and a garage showed if these facilities were present, while the size of the garden also indicated how large the garden was in reality.

Spence and Parr (1991) were able to show that the icon was able to offer superior performance when compared to a textual representation of the same data. As explanation of this, Spence & Parr state the fact that the icons made information highly salient that was crucial to completing the task.

Information Cities

A more ambitious 'iconic' representation has been demonstrated by Young (1996) who illustrates how the metaphor of a city can be used to represent software information. The 'SoftCity' visualisation contains buildings, streets, districts and people onto which information is mapped specific to the aspects of software maintenance. Each building represents a particular source code file, with each floor in the building representing a function definition in that file. Large buildings therefore take on the appearance of skyscrapers while small source files are less conspicuous. Revisions are shown in terms of windows and the age of functions is shown by the age and style of brickwork in the building. As additional functions are written to a file, the corresponding building receives an additional floor in a more modern style of brick to highlight and make the change explicit. It is also possible to divide the city into a number of districts depending upon particular criteria. For example a 'downtown' area can be created of files which have received many revisions.

Figure 2-7: SoftCity Visualisation (Young, 1996)

These heavily revised files would take on the appearance of run-down buildings which have been successively repaired. Young (1996) makes the point that the metaphor takes on additional power with regard to software programmers not wanting to venture into the downtown area which would be much harder to de-bug given the more complicated nature of the revisions there.

The visualisation therefore enables the knowledge of real-world attributes, such as a run-down area that is undesirable, to be used to guide understanding of the code within a particular software program. A further advantage of the visualisation is that it provides a clear way of incorporating a large amount of information in a coherent way within a three dimensional organisational space.

2.2.3 Semantics of Multidimensional Icons

The importance of semantic issues has only been touched upon so far in connection with the idiosyncratic meanings some users may ascribe to certain parts of the face. The issue of semantics in general however, is a central theme of multidimensional icons. The ability which icons have to explicitly refer to real world objects and the relationships inherent within them means that an approach may be useful which takes full account of this.

So far approaches to mapping meanings between concepts and icons have been somewhat unstructured. Gnadesikan (1977) for example, points out that "an important issue in connection with Chernoff's scheme that needs further study is how to go about associating the variables with different aspects of a face in any specific application. Developing guidelines for this would be useful." The same it can be argued can equally well be said for any other type of multidimensional icon. So far in the literature, the assigning of variables to physical aspects of the icon has been done very much by intuition without any view to a theoretical grounding. Moriarty (1979), Stock & Watson (1984) and Chernoff (1973) therefore took an informal decision on which mappings they felt would be most advantageous. Kleiner & Hartigan (1981) on the other hand attempted to group aspects of data with high similarity close together. The semantics of the data therefore played no role in the form of the actual icon. Spence & Parr (1991) choosing a house icon to represent housing data, attempted to map visual aspects of the icon to their real world counterparts. A garage was therefore part of the icon if one existed in the actual house, while the number of windows represented the number of bedrooms for example.

This is not to say that the mappings chosen were not effective, but rather that these approaches are limited within the domain, and in the case of Spence & Parr to the type of icon. The goal of the use of Chernoff faces was therefore to cluster large groups of companies according to rather rough categories. In the case of Moriarty and Stock & Watson the goal of using the representations was to separate healthy companies from unhealthy companies (mapped to a happy or sad facial expression). If the judgement dimensions were to change, so that bankruptcy was no longer the issue, and it was not clear at the outset what the goal state was, then the use of this informal mapping approach would be limited, as it would no longer be clear which concept variables should be mapped to which visual elements. The goal of castles and trees was somewhat different in that it was to allow correlated variables to be clustered together so that they were perceptually easy to spot. In this case, the goal of how to map is clear – related variables should be close together. The approaches are therefore useful for allowing bankrupt companies to be spotted, or for allowing correlated clusters of variables to be identified, but the icons are not designed to be used in a wider range of circumstances.

Other icons such as the polygon, are more generally applicable, but are relatively neutral and do not contain much in the way of semantic information. Approaches are not therefore given of how variables can be mapped to visual elements. Spence & Parr's (1991) icon in contrast is highly specific and designed to be used in tasks where a range of different criteria becomes increasingly or decreasingly important. In this case however the icon used is particular to the data domain – namely housing information. If the domain was to change to financial information then, where no clear real world object exists onto which to map this information, then it is not clear from their approach whether a house could be used, or how to map this information from concept to portrayed object.

The question also needs to be raised as to how important thoroughness of mapping is. In the case of the house icon used by Spence & Parr then, an association certainly exists between the subject the data is relating to and the icon used for portraying this data, however little is said about why a window is used to represent a bedroom or why house colour should equate to price. House prices are not determined by colour in the real world so why should such an association be useful? Might it not on the contrary be confusing in some instances for precisely that reason? Such questions are not unimportant: Houses, faces, pies, and cone trees or any other object which might be used to represent data, all have real world connotations which may or may not be acknowledged by their original designers when they are mapped to what they represent. If there is no clear convention then users have to employ their prior knowledge to try and understand how the representation works. Even if it is understood once explained it may be the case that these prior associations are too strong to suppress.

It is argued here that a more rigorous method of assigning concepts to visual iconic elements is needed if icons are to be used in tasks where a clear hierarchy of importance does not necessarily exist. One area of psychology which deals explicitly with this issue, namely analogical processing, will be outlined next.

2.3 Visual Analogy & Abstraction

The use of analogy, whether visual or not, as an explanatory or reasoning tool is common in everyday life. The most basic example is perhaps in phrases such as "He just got a pay rise", or "Ten is a lower number than 20". In these instances verticality is used to express changes in number with 'rise' or up for increase and down or 'lower' for a decrease. Such use is systematic and highly structured – lower quantities are therefore always represented by phrases describing the low end of a vertical scale, while larger numbers are represented by numbers describing the higher end. This is a basic example of analogical structuring for representing information (Lakoff & Johnson, 1980).

Gentner & Markman (1997) provide a more complex example of the role of analogical processing by citing Johannes Kepler and the pre-cursor to gravity which he proposed (formalised by Isaac Newton 80 years later). Prior to Kepler the best existing model to explain the course of planets around the sun was that they were impelled by spirits or souls. As the planets on the outside moved more slowly than those on the inside, the argument previously given was that those spirits of the outer planets were weaker than those of the inner planets. Kepler's new proposal was that there was one power emanating from the sun which moved all the planets. A major problem for this proposal from the perspective of physical science was that it requires action to be propagated at a distance. In answer to this question, Kepler proposed the analogy of light, and how this also functions at a distance with decreasing intensity. This new motive force also had in common with light the fact that it was undetectable between its emanation from the source and the illumination of the target.

In explaining planetary attraction in such a way, Kepler employed analogical structuring both in terms of the reasoning towards and explanation of his theory.

Knowledge of the structure and relationships in a known (source) domain, were therefore used as a framework to understand a new, as yet unknown (target) domain. Gick & Holyoak describe the process of using analogy in problem solving as working by abstracting the relational structure common to a particular set of instances. To do this, the old known domain is abstracted into a schema which maintains the essential properties of the domain. New domains can then be mapped onto the schema.

There is a wide body of evidence which suggests that analogical processing is central to cognition. These include problem solving (Gick & Holyoak, 1980; Gentner & Gentner, 1980), linguistics (Lakoff & Johnson 1980; Gibbs & O'Brien, 1990) and problem formation (Bassok et al., 1998).

The use of analogy in the visual domain will now be described.

2.3.1 Mechanisms of Visual Analogy

The process of analogical structuring also extends to the visual domain. The simplest example is a bar or line graph where 'up' almost invariably equates to 'more' in terms of quantity, mirroring the linguistic use of verticality. Gattis and Holyoak (1996) have shown that the understanding of higher-order concepts is also similarly structured. This has been demonstrated in a study, which investigated the mapping of conceptual relations to spatial relations in a visual reasoning task. In this case accuracy was greatest when judgement on the rate of change, the variable in question, was based on the visual mapping steeper = faster).

An important question is - what makes a 'natural' mapping? The fact that 'up' or 'steeper' on a piece of paper can be equated to a concept in the real world is often taken for granted, however the real world concept of temperature change and the external representation in the form of an angled line are not the same thing. The fact that the mapping appears 'natural' is perhaps more a comment on the facility with which humans are able to accomplish the mapping process. How this mapping process is achieved has been described as consisting of different mechanisms which can be summarised in terms of the following four descriptions (Gattis, 2001). These are Iconicity, Associations, Polarity and Structural Similarity.

Iconicity

If a representation preserves some of the perceptual features of that which it represents, then it is functioning along the principles of iconicity. This was a predominant feature of early writing systems such as hieroglyphics where the representations often contained some visual similarity to the objects which were being described. In more modern times, maps or room plans are the most obvious example of where iconicity is employed. As Gattis (2001) points out however, iconicity is not sufficient when more abstract notions need to be represented which do not exist as physically visible entities. In such cases the principle of association needs to be employed.

Associations

An example of the principle of association at work is normally readily visible to most users of computer monitors. Contrast or brightness are not physically visible entities and hence are represented by an icon working on the principle of association. Contrast is therefore normally represented by a circle which is vertically divided into one light and one dark segment, while brightness is represented by a 'sun' like figure. Brightness does not look like a sun, but can readily be associated with this meaning in the context of computer monitor controls. Through this principle of association, abstractions can therefore be represented. As Gattis points out, associations are so common and transparent that the existence of the principle can often be overlooked, the assumption being that the representation functions solely through displaying a property of the concept itself. The origin of the mapping is indeed likely to have been rooted in perceptual experience – hence a greater amount of a particular substance will take up more space and this maps conveniently onto bigger, thicker or higher in representational terms. The principle of association comes into play however through the fact that these mappings do not have to be applied exclusively in the context of their perceptual origins. 'Higher' can therefore be applied to 'hotter' without questions being raised as to the physical reality of the pairing.

Polarity

While associations are held to be based on experience, there is also research that suggests that another factor, namely polarity must be taken into account.

The concept of polarity is based on the fact that there is an organisational structure underlying many perceptual and conceptual dimensions – which manifests itself in a 'marked' to 'unmarked' continuum. The opposing adjectives 'good' and 'bad provide a clear example of this. 'Good' in this case is the unmarked term as the question "How good is it?" can be asked without any particular connotation being raised. The question "How bad is it?" on the other hand contains a negative connotation and is therefore the 'marked' term. The structure of dimensions with marked and unmarked extremities is extremely common linguistically and evidence exists which shows that this becomes more important with age. For example it has been shown that older children and adults will pair perceptual aspects in accordance with the concept of polarity with linguistically marked terms being paired together, while young children consistently use a different system which does not pay heed to such underlying organisation (Smith & Sera, 1992). Other studies also confirm the importance of polarity with for example the use of marked terms giving rise to longer reasoning times (Clark, 1969). Polarity can therefore be considered a factor separate and more specific than that of association which has important implications for the mapping process.

Structural Similarity

Iconicity, Associations and Polarity are powerful and important constructs, Iconicity constraining based on perceptual similarity (or resemblance), associations based on attribute or property similarity (without actual resemblance) and polarity constraining based on weighted valence. These mechanisms do not however account fully for the ease with which complex representations can be used to aid reasoning. Gattis (2001) cites structural similarity also as a way of constraining mapping – this being when the representation shares relational structure with the concept being represented. Elements are therefore paired to elements, relations to relations and higher order relations to higher order relations.

In complex or even simple representations there may be a number of possible representational continua which conflict with each other. Gattis and Holyoak (1996) for example demonstrated that when a conflict exists between the iconic representation of 'up' on the graph equating to 'up' in the real world, and the association of line angle corresponding to rate of temperature change, it is the non-iconic association which proves most effective when temperature change is the variable being queried. Clearly there must be an additional organisational mechanism at work. This has been coined 'structural similarity' (Gattis, 2001).

Structural similarity refers to the similarity in structure between the entity being represented and the representation. This has been shown to be easily assimilated by people who appear to actively seek a similarity of structure between the representation and the represented. As such the concept is virtually identical to the concept of structural alignment (Gentner & Markman, 1997) which itself is composed of three constraints: structural consistency, relational focus and systematicity:

Structural consistency refers to the alignment of elements between the base and the target. Two factors which are key to structural consistency are that of parallel connectivity –which requires that matching relations have matching arguments- and one to one correspondence –which requires one element in the base to match to one element in the target. If the two representations are structurally consistent then in order for them to be processed analogically with any meaning, a relational focus must be maintained. The key element of the target representation must therefore feature in the same role as its counterpart in the base representation if analogical processing is to produce meaningful results. Finally the relations between the two representations need to be matched in a systematic way by higher order constraining relations, so that meaning is attributed to the relationships and extrapolations can be made.

Gattis (2001) has shown the importance of structural similarity by demonstrating that when adults are asked to interpret novel spatial schemas, physical objects are chosen to represent conceptual elements and physical relations to represent conceptual relations. This is in accordance with the claims made (Gentner 1983; Gentner & Markman, 1997) that analogy and the structural relations, which are inherent in this, are central to human thought. External spatial representations such as graphs or information visualisations can therefore reasonably be considered to be subject to the same processes.

These mechanisms will act in concert to produce what is considered to be a 'natural' mapping. The explicit visual representation of other objects therefore has the potential to harness prior knowledge to play a role in the effectiveness of visual representations which is just as important as that demonstrated in the other domains of linguistics, problem solving and problem formation. It can be argued that the principle of iconicity and associations can be used as a guide to determine individual aspects which should feature within a Multidimensional icon as well as to help determine what should correspond to a 'high' and a 'low' level of a particular variable. Structural similarity can help in making a decision as to what elements within the overall form should map to particular variables – by ensuring that there is an equivalent relationship between these variables as in the real world concepts. In this manner an understanding of the 'old' (the visual form being shown) can be referred to in order to access the meaning of the 'new' (the concept being represented) more quickly.

The listing of these aspects describing what makes a good visual analogy, allows a quasi-quantitative continuum of visual analogy to be constructed for a given concept, with visualisations incorporating none of these attributes lying at the 'low' end of this continuum and visualisations heeding all of them lying at the 'high' end. While it is most likely a difficult task to order all potential visualisations in a strictly defined order according to this continuum, a degree of ordering is nevertheless possible. This will form a key foundation of the experimental work in this thesis.

2.4 A Psychological Context to Visual Analogy

Card et al (1999) in their definition of information visualisation refer to the term 'cognitive amplification' as being a defining feature of information visualisation. By cognitive amplification it is meant that normal unaided human abilities can be improved by representing information in a more perceptually amenable way and configuring representations such that less cognitive effort is required to make whatever decision the representation is being employed to help with.

Information visualisation has the potential to help humans manage their limited perceptual and cognitive resources in a number of ways which often act in concert. There include making more effective use of innate perceptual abilities, acting as an effective external support to internal processes, aiding in the dynamic development and use of appropriate mental models in addition to harnessing prior knowledge of other appropriate but potentially unrelated areas as already discussed. These areas will now be described in more detail.

2.4.1 Perceptual Mechanisms

The make-up of the eye is such that it allows for two approximate processes of perception to run simultaneously. These can be divided very roughly into the concept of seeing and the concept of perceiving. Seeing can be defined as the process of paying attention to something, where the object is being scrutinised in detail and can be clearly seen, while perceiving also involves visual awareness – however this awareness is held to be largely unconscious, requiring little or no effort. The purpose of perceiving is to maintain a constant awareness of the environment to determine if anything is worthy of actually being attended to and 'seen'. At any one time we perceive much more than we actually see. This distinction between the two is only very approximate (Shiffrin, 1988) however it is useful in as much as it puts forward the concept of conscious visual processes and (near) unconscious visual processes, the distinction between which is one of the keystones in the theory of why information visualisation is advantageous.

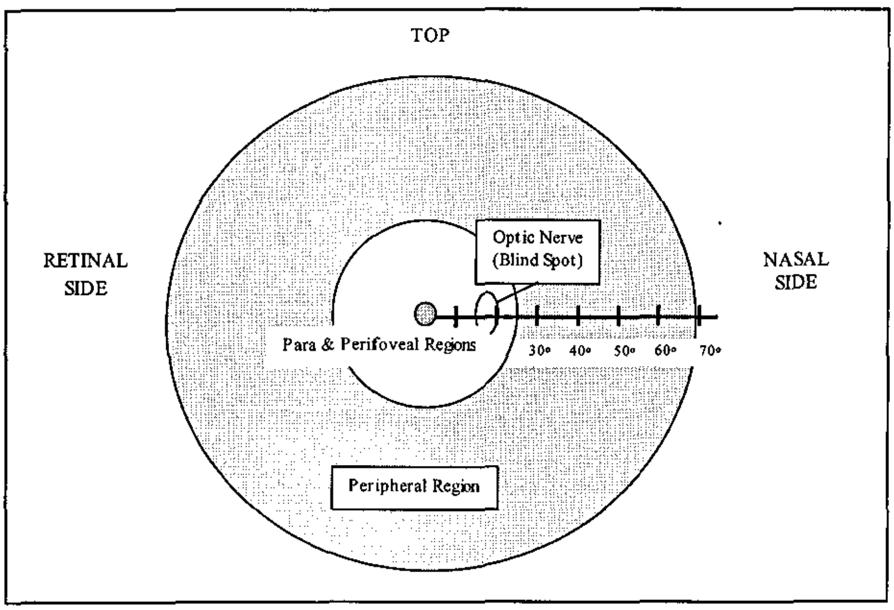


Figure 2-2 – Geometry of the retinal surface (from Card et al., 1999)

The distinction between conscious and unconscious processes is reflected in the anatomy of the eye itself which consists, most basically, of a movable lens which focuses a visual image onto a bed of 125 million photoreceptors. These photoreceptors are of two different types: 6.5 million colour detecting receptors known as cones, and 118.5 million receptors which function only in black and white, known as rods. The density with which these photoreceptors are grouped varies according to which particular part of the retina, they lie upon. The retina – the light sensitive part of the eye- can be divided into distinct regions: the peripheral region, and the fovea.

The density in which these cones are grouped depends heavily upon where exactly on the retina they lie. In the peripheral region rods, which are most effective at detecting changes and marked features of the external environment, predominate. In contrast to this, cones are more common in the foveal region, to the extent that they are 27 times more dense in the very centre of the foveal region (foveola). Resnikoff (1987) states that as the number of cones per neuron is 8:1 when compared to 1:1 in the periphery, the actual visual resolution of the foveola may be up to 200 times greater. There is therefore clearly a two-tier system in operation with one section of the eye being designed to take in detail and the other designed to use pre-attentive processes to detect strong patterns of size, intensity and colour contrast, in order to prime the visual system as to where detailed attention should next be directed (Julesz, 1981).

This design has important implications for the design of an effective information portraying medium. Card et al. (1999) conceptualise this perceptual dichotomy in terms of controlled processing and automatic processing. Controlled processing primarily works through the fovea and is detailed, serial, low capacity, slow, able to be inhibited and conscious. Automatic processing on the other hand works mainly through the peripheral regions and is superficial, parallel, high capacity, fast, cannot be inhibited and unconscious. Text is one representation modality which makes almost exclusive use of controlled processing. It may be possible to process automatically how much text remains to be read, but the majority of information can only be garnered via a detailed but slow conscious channel. Visual portrayal on the other hand has the potential to make use of fast, automatic processing by exploiting the variety of visual cues which can easily be incorporated into information designs (Card et al., 1999). Information can therefore be taken in via the slow, detailed and conscious channel, while at the same time (if an appropriate form and presentation method have been chosen) a significant amount of contextual information can also be displayed relating not just to the amount of information but also the relationships between elements and depending on the coding chosen, other qualitative factors.

2.4.2 Search, Recognition & Inference

The fact that an increased amount of information can be laid out in a way that facilitates the gaining of an idea of context is an important foundation of information visualisation. An account of the cognitive processes involved is also needed however. Larkin & Simon (1987) describe the process of using a visualisation in terms of three sub-processes, namely Search, Recognition and Inference. Visual representations, they argue consist of both the external data structures as well as the internal programs which operate on them. Using a visualisation is therefore a matter of using the internal productions on the external data structures which takes place according to the three stages of: search, recognition and inference.

Search is the first step and involves finding the relevant elements from all those which may be represented in a given sentence, diagram or data set. In a sentence or sentential representation – the relevant elements are located in different positions. A cognitive overhead is therefore imposed while one element has to be maintained in memory, and the other searched for. Visual representations allow for certain elements to be represented in one position. Limited attention resources can therefore be easily focussed at a relevant location. The fact that a rabbit is white and furry, to give a simple example, can easily be represented in one location in a visual representation. In sentential form, the descriptions are separated and therefore have to be matched together.

Once a relevant set of elements has been found. The meaning of these then has to be recognised. A set of x and y co-ordinates for example can be represented both in tabular form and as geometric points on a graph. Larkin & Simon point out that visual entities such as smooth curves, maxima and discontinuities can be readily recognised in the graphical representation, but not in the tabular one. This stage requires knowledge however or to paraphrase Larkin & Simon, the situation needs to be represented in a way which matches existing productions. The complaint of physics professors that students do not make enough use of diagrams can therefore be explained by the fact that the productions to make use of these are missing. This being the case, any such diagram is largely useless.

Finally once a given set of elements has been found and recognised, inferences or cognitive conclusions can be made from them. Again diagrammatic forms can be useful here through the fact that they can facilitate powerful inference processes. However, Larkin & Simon state that such powerful inference processes are not necessarily exclusive to diagrams (p.71) – "Inference is largely independent of representation if the information content of the two sets of inference rules [one operating on diagrams and the other operating on verbal statements] is equivalent. Bauer & Johnson Laird (1993) however illustrate that in double disjunctive reasoning instances, e.g.:

> "While the event is occurring:
> Raphael is in Tacoma or Julia is in Atlanta, or both.
> Julia is in Seattle or Paul is in Philadelphia or both.
> The event is talking place.
> What follows?"

diagrams representing the problems in terms of electric circuits can have a beneficial effect over more arbitrary diagrams on the number of correct inferences made and the speed at which these inferences are made. The difference in performance of the diagram types suggests that the effective diagrams highlight the information used in reasoning with internal mental models and provide external support in managing the relations in working memory (Gattis & Holyoak, 1996)

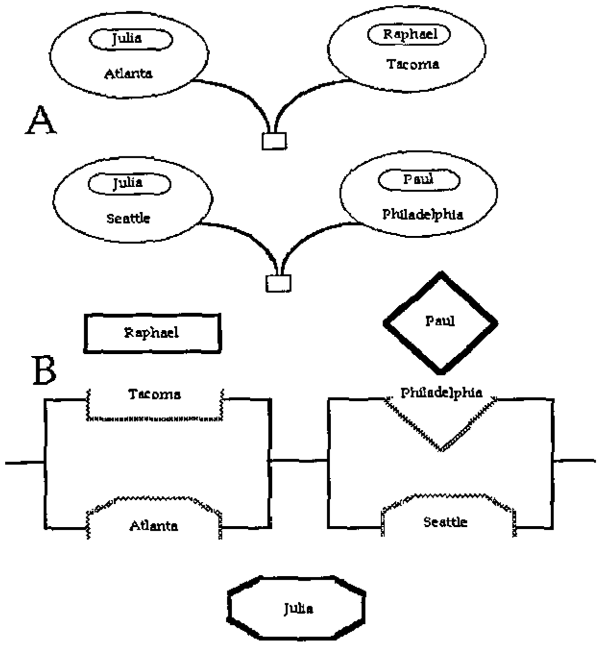


Figure 2-8: Representations used in Bauer & Johnson Laird (1993) showing (A) the less successful & (B) the more successful representations

The utility of Larkin & Simon's theory is that it posits an explanation as to the benefits of pictures at both a mechanical (searching) level, as well as at a cognitive level (recognition and inference). It also provides an important explicit link between the internal and the external. Larkin & Simon themselves state however that they are not specific with regard to the role of mental imagery. They also speculate that mental images play a role in problem solving which is similar to the role played by external diagrams, and that this role is played by the two "in concert" (p.97). Before considering how this role might be played out in further detail, the manner in which mental imagery or mental models are proposed to work will first be discussed.

2.4.3 Mental Models

A mental model is an internal 'working model' of a real world phenomenon. In terms of diagrammatic usage, mental models appear to have two roles. First, they are a mechanism through which inferences can be made from the use of diagrams, and second, they are also the result of this inference process. As such a mental model is continually consulted and updated.

According to Johnson Laird (1989) this model can be either long-term or short-term and corresponds to the structure of the situation it represents. Mental models possess a number of characteristics which are of importance to information visualisation. Most importantly, they represent the structure of their domain in an explicit manner which is not tied to any specific modality. Information within an internal mental model which represents a certain situation does not represent the complete situation but rather only relevant aspects of this situation. The defining feature of a mental model is that the structure of relations within it, correspond to the structure of the relationships in the situation being modelled. These represented relations are by definition explicit. Mental models are held to be able to incorporate information from many different modalities as well as information that corresponds to abstract as well as concrete notions which may be communicated in propositional form (Johnson-Laird, 1983).

A mental model is a working model which is both consulted, and updated based on the current state of understanding of this phenomenon. The updating process itself, allows noticing, which means that elements surrounding the current focus of attention are also brought to attention or primed. (Glenberg & Langston, 1992). This takes place within the context of limited working memory resources. Mental models themselves are however a way of managing finite resources more effectively, as they incorporate only the aspects of information deemed important at the time. Information which is considered redundant can therefore be deleted just as well as information considered important can be incorporated into the mental model.

The description of mental models has largely been derived from work on the facilitative effects of pictures on text comprehension, however the manner in which mental models work in the context of information visualisation can also be presumed to be similar. A mental model of the relationships in a given data set can therefore be formed from the visualisation. This model can then be updated based on closer inspection or interaction with the representation. A potential benefit which an appropriate information visualisation allows in this regard then, is that an opportunity is provided for the formation of mental models which can more easily be formed or updated.

The dynamic updating of mental models, based on interaction with the external is an important aspect of their use, and was only touched upon by Larkin & Simon. It is of considerable importance for a complete understanding of information visualisation however and the benefits which it might bring. This aspect will now be focussed on in more detail.

2.4.4 Internal –External Mediation

Larkin & Simon (1987) made a link between the external (i.e. the representation) and the internal (i.e. the processes which operate on external representation). Here, their definition of the internal was limited to the productions that operate on external representations. They also offered as a parting note however, the speculation that mental imagery can also play a central role in diagrammatical use which takes place in concert with external memory (i.e. the representation). Scaife & Rogers (1996) point out that little is known about how this interleaving takes place and propose three mechanisms by which it takes place, these being cognitive offloading, re-representation and graphical constraining.

Computational offloading

Computational offloading refers to the manner in which graphs facilitate the 'offloading' of mental effort from the user to the external representation being used. This works through a number of channels. Larkin & Simon (1987) for example indicate that the greater efficiency in geometry problem solving for diagrams over sentential forms is through their ability to support direct perceptual recognition of geometric relations. Solutions can therefore be read instead of needing to be mentally formulated, which would require greater computational effort. In addition, graphical representations make greater use of location as a representative element of information. This facilitates searching for information as relevant information is often grouped together. This is in contrast to sentential representations where the words relevant to a particular problem may not actually be grouped together. This combination of explicitness and location combined mean that diagrams making use of these aspects can be more effective forms of cognitive support than non-diagrammatic representations.

Re-representation

Re-representation refers to how different external representations having the same abstract structure can change the ease with which problems are solved. Zhang and Norman (1994) describe carrying out the same multiplication task using roman or Arabic numerals. Both represent the same formal structure, but the former is much harder for people used to working with the decimal system to reach the same solution (LXVII x X is much more difficult to solve than 68x10). It is important to bear in mind that the fitness of any given representation is highly dependent upon the task. The decimal system is therefore most optimal for the multiplication task described above, however in some cases, for example a simple addition task, the roman system can be easier (e.g. I + II = III) than the decimal system (e.g. 1+2=3). A number of other authors have been more specific as to how re-representing a problem can be helpful. Wason & Shapiro (1971) for example report on how an abstract problem reliant on the manipulation of numbers and letters can be eased when it is re-represented to include real world knowledge in the form of towns and modes of transport, leading from an accuracy rate of two out of sixteen to ten out of sixteen. Kotovsky, Hayes & Simon (1985) also elaborate on the mechanisms of re-representation in a monster isomorph of the 'Tower of Hanoi' problem. They were able to show that the problem could be more easily solved when the monsters moved different sized balls among themselves rather than when the balls the monsters were holding suddenly transformed into a different size. It was also concluded that spatial or positional information holds a privileged role with regard to problem solving. In their study it proved easier to keep track of changes in position than to track changes in non-spatial attributes of an object.

Graphical Constraining

Graphical representations are able to limit the kinds of inferences which are made about the underlying worlds which they represent and this is described as 'graphical constraining'. The characterisation is a term developed by Stenning & Oberlander (1995) in their work on the effectiveness of diagrams in the solving of logic problems. The central idea to the theory is that relations between graphical elements in a graphical representation are visually able to show their relations in a way which re-enforces correct interpretations and discounts incorrect interpretations. The closer the coupling between the representation and the underlying world, the more effective the inferencing.

Scaife and Rogers acknowledge that there is a degree of overlap between the terms cognitive offloading, re-representation and graphical constraining. However they view them more as complementary - computational offloading highlighting the benefit of graphical representations, re-representation relating to their structural properties and graphical constraining to possible processing mechanisms.

The acknowledgement of the role of the exterior in information visualisation raises important issues of how people use information visualisations – bringing the process of cyclical interaction between the user and the representation more to the fore. Information visualisations are not therefore passive information repositories, but rather can actively be used as tools to achieve a particular cognitive task.

The concept of cognitive offloading is especially important in this regard as a way of describing how this takes place. O'Malley & Draper (1992) for example describe the difference between knowledge which users need to internalise and that which is present in the display and does not need to be learnt. A number of instances have also been described in the literature as to how graphical representations are interacted with to aid memory load in a task specific manner. Anderson (1960) therefore reported that biologists add marks to paper based metroglyphs when using them in order to highlight distinctive specimens, and goes as far as to propose guidelines as to the most effective form such marks should take – namely small pencil dots which do not interfere with the scanning of the data.

Spence & Parr (1991) also noted how participants actively used a number of different strategies to shift cognitive load on to the visualisation and make a multi-attribute optimisation task easier. The task involved identifying a house out of a collection of many, which best fitted certain pre-ordained criteria. Some participants therefore used 'positive' marking to highlight items which appeared to meet certain criteria, while others negatively crossed off items which did not meet the requirements. Another strategy was to mark the 'best-to-date' candidate, so that the task was changed from considering several different in many different icons, to comparing these variables in just two icons. Spence & Parr also noted the task of choosing an item with the optimum combination of variables was often reduced to focussing on one or two important variables which were perceptually salient, and scanning the icons featured only in terms of these features. The visualisations themselves were therefore used as an aid to reduce the complexity of the task, admittedly at the expense of accuracy. This strategy of trading off accuracy for time and effort is also one that has been identified by Vessey (1994).

2.5 Human Factors Research

A number of reasons have been presented as to why visualising information should be an effective way of presenting information, more so in many cases than presenting it in numerical or tabular form. Card et al., (1999) summarise these reasons in terms of 'amplifying cognition' stating that information visualisation can 1) increase the memory and processing resources available to users, 2) Reduce the search for information, 3) Use visual representations to enhance the detection of patterns, 4) enable perceptual inference operations, 5) Use perceptual attention mechanisms for monitoring & 6) Encode information in a manipulable medium.

Given this list of benefits however, it is important to bear in mind the complex interaction of outside factors which combine to make up an effective visualisation in an applied setting. As a way of demonstrating this, a summary of the empirical literature will be presented which describes empirical studies carried out on graphical representations of abstract quantitative data.

2.5.1 Graphical Formats

Graphs represent abstract information in visual form and as such are relevant to an understanding of information visualisation. Research on graphs will therefore be taken here to be synonymous with research on limited aspects of information visualisation. The majority of studies concentrating on graphical effectiveness have tended to focus on comparisons between graphs and tables over a variety of parameters such as perceptual efficiency and decision making. These will now be outlined.

2.5.2 Perceptual Efficiency

One of the most fundamental ways in which the effectiveness of graphical displays can be investigated is in terms of the efficiency with which information can be extracted from a graph. Studies such as that of Legge, Luancho & Gu (1989) have looked at this and measured the efficiency with which observers can detect differences in the means or variances of pairs of data sets sampled from Gaussian distributions. Efficiency was compared using numerical tables, scatterplots and luminance coded displays. It was found that efficiency was highest for the scatterplot (at approx. 60%) and was only weakly dependent on sample size and exposure time. These results have led to the suggestion that parallel perceptual computation takes place with graphs in which a constant proportion of the available information is used. As such it would seem that a strong case could follow for the usage of graphs in numerical presentation. Legge et al. state that their findings "extend those of Cleveland (1985) and Cleveland & McGill (1985) by quantifying the superiority of graphs over numerical tables". Cleveland & McGill point out that the great advantage of graphical displays over numerical tables is due to the capacity of human vision to process global pattern features at a glance described by Julesz (1981) as "pre-attentive". Measuring the "superiority" of graphs purely in terms of means and variability discernment is of limited use however, as is demonstrated in a series of studies investigating decision making and graphical / tabular formats.

2.5.3 Decision Making

The literature on the facilitative effects of graphs on decision making turns out to be considerably more complex. De Sanctis & Jarvenpaa (1989) for example compared bar graphs against tables in the context of financial forecasting and found some support for the fact that graphs allowed more accurate decisions to be made. Dickson, De Sanctis & McBride (1986) in contrast found that graphical displays in the form of bar graphs and line plots in data interpretation accuracy and decision making tasks offered no significant advantage. Importantly however, the study raised the issue of task demands and the contribution these make to effectiveness. The main conclusion raised from the investigation was that results from one shot studies which paid insufficient heed to the exact demands involved in the decision making tasks of their experiments may be nothing more than situationally dependent artefacts.

Indeed, the importance of paying sufficient heed to the exact demands involved in any evaluation of graphics vs. non-graphics cannot be over-emphasised and goes a long way to explaining the disparity in results which have been generated over the years. Jarvenpaa & Dickson (1988) for example in a review of the literature conclude that there is at best "partial support" for the hypothesis that graphic presentation improves decision making. Ives (1982) also finds mixed results when reviewing the area and summarises that some of the extravagant claims favouring the graphic presentation format are "considerably overstated". This disparity in results is perhaps best summarised by a survey made by DeSanctis (1984) who found that out of 29 studies, twelve of the 29 were actually found to favour tables, ten found no difference and only seven found graphs to be more effective. Clearly the mere use of graphics in a data representing situation does not automatically lead to any benefit being gained. In fact, it could be surmised from the DeSanctis study that it may actually be detrimental. The clear message from such studies is that representation use is heavily task dependent.

2.5.4 Effectiveness of Multidimensional Icons

The question of task dependence is one that is also reflected in empirical work on multidimensional icons. Research into multidimensional icons has been somewhat more focussed than research into more general representational formats stemming largely from the fact that the initiators of the research are by and large the same people who are advocating the utility of this representation in the first place. Hence the tasks which have been explored have been largely those for which the representation has been specifically designed. The instances of successful use of multidimensional icons therefore outweigh instances where their success has not been proved.

Examining first the effects of richer icons such as faces and houses in comparison to traditional numerical or graphical formats, Moriarty (1979) and Stock & Watson (1984) found that multidimensional icons are more useful than bar graphs and numerical representations of the same data in a task where an overall impression of the combination of variables in a dataset is needed. Spence & Parr (1991) also demonstrated that multidimensional icons are more useful than textural representations of the same data in a task where 'best–fit' candidates needed to be identified from a collection of many. MacGregor & Slovic (1986) also found a marked advantage of using faces over traditional graphical formats. In terms of more abstract multidimensional icons, Goldsmith & Schvaneveldt (1985) found that Integral displays (of which the face is an example) are superior to both 'separable' bar graphs for both complex and simple stimuli both where judgements combining different aspects of data are required as well as judgements on singular data aspects.

Nevertheless this superiority is not universal. Goldsmith & Schvaneveldt (1985) for example found in a pilot study that faces are inferior to bar graphs for representing multiple information cues. The inventor of the face, Chernoff, also qualifies his advocacy of using faces with the remark that faces are unlikely to have potential for providing the facility for doing relatively accurate calculations, although he did not test this empirically.
MacGregor & Slovik (1986) after having investigated the use of faces among other ways of representing data also conclude that graphical formats appear to facilitate judgemental performance in some contexts but not in others.

2.5.5 Why Such Diverse Findings?

If the literature outlined up to this point is considered in its entirety, we can see that the search for 'effectiveness' is a complex matter. Graphs for example appear to be more perceptually efficient (Legge, Luancho & Gu, 1989) and better able to make use of pre-attentive mechanisms (Cleveland & McGill, 1985). In some studies graphs also support more effective decision making. However, in approximately 50% of studies, tables produce equal or better results with regard to decision making. In addition to this there is surprisingly little consensus as to exactly which tasks graphs and tables best support (De Sanctis, 1984; Vessey, 1994; Yu et al., 1998). In the case of multidimensional icons, claims regarding their effectiveness have been somewhat more conservative, based perhaps on the fact that it is clearer that their benefits are not universally accessible for any task requiring the display of numerical information.

This variety in the overall literature suggests that there are variables at work which are not obvious and hence easy to overlook. The complexity of the task at hand is one that has been recognised (Jarvenpaa & Dickson, 1988) however given that effectiveness differences are still apparent after this has been considered, it would seem that there are still more factors that need to be taken into account. A number of commentators have offered their own theories as to what these are, and these vary from the addition of an extra variable into what can almost be seen as 'an effectiveness equation' (Yu et al., 1998; Meyer, Shinar & Leiser, 1997) to theories which deal with users' choice of strategy in response to the wide range of variables which comprise the decision making task (Vessey, 1994).

Yu et al. (1998) for example present a simple example of an additional variable which needs to be considered in all format comparison studies and consider the additional interaction of data type (e.g. Nominal, Ratio, Normally distributed etc.), with task type and graphical format. They present this in the context of an 'alignment framework' which is described as a prescriptive framework allowing optimum choices to be made as to the most effective representation type in a given instance. It can be argued however that this does not go far enough in as much as only a small number of graphical formats are considered in combination with an under-specified collection of tasks. In addition it can be argued that a prescriptive framework requires more than three interacting variables to be taken into account.

Coll & Coll (1993) develop this line of argument further and argue that it is not necessary to take just one additional variable into account to adequately explain the diversity of results which exist, but that many must be considered. To illustrate this point, Coll & Coll take the analogy of a spoon and fork and compare the majority of studies described so far as asking the equivalent of the question:

> "Which is better for eating, a spoon or a fork?"

The answer they state is that it depends. If the question is tested with soup then the spoon wins and if it is then tested with steak then the fork will win. When tested with potatoes there may be a draw, however in this case preferences due to conditioning come into play. This analogy is useful as it demonstrates the importance of task as a factor governing effectiveness, but in addition it also illustrates the role that individual differences might play.

Coll & Coll elaborate on such factors and have constructed a classification of 16 variables proposed as relevant to efficacy and choice of data presentation. These variables fall broadly into five groups and are: User variables, Task variables, Presentation variables, Data variables & Work Group variables.

User Variables
Personality / Psychological Type
Education / Training specialty
Level of User Expertise with the Target Problem
Level of User Expertise with the available system
Task Variables
Problem Requirements
Problem Complexity
Amount of Structure Available for Solving The Problem
Time Available For Solving The Problem
Presentation Medium Variables
Quality / Richness of The Display
Capacity for Restructuring The Display
Time Between Display Request and Display Presentation
Data Variables
Amount of Data Needed
Amount of Data Available
Variability of Data Available
Complexity of Data
Work Group Variables
Work Group Consensus

Table 2-2: Sixteen Variables Affecting Choice of Tables & Graphs (Courtesy of Coll & Coll, 1993)

An alternative approach to explaining why the body of literature as a whole provides such diverse results can be found in the cost-benefit theory (Vessey, 1994). This distinguishes between strategies which are employed to make use of information being presented, and the perceptual and cognitive processes of which these strategies are comprised. Vessey argues that the majority of previous studies have focussed on the level of processes and not on strategies primed by the demands of various experimental tasks. As such the theory concentrates at a higher level than the majority of studies in that it does not concern itself with which format of information is most effective at the most basic level, but views this in the entire context of the task being performed. The prime argument of the cost-benefit theory is that users of particular information presentation formats will adopt a strategy of usage which yields the best balance of speed / accuracy and effort. The importance of format is therefore superseded by the demands of the task at any particular instance. Vessey points out that such a viewpoint successfully accounts for the majority of findings in the graphs vs. tables literature, although many studies do not provide enough detail about the exact task involved to permit meaningful evaluation. Winn (1987) is also of the same opinion and states that a measure of the ability of students is their proficiency at selecting appropriate learning strategies and using them. Spence & Parr (1991) also comment on the fact that many of the subjects in their experiment on Multidimensional icons employed a simplified strategy (i.e. looking for large black areas on a clock) when making multivariate judgements.

These meta-evaluations may on first sight appear to add yet more complexity to an already over-complex situation. However, on closer inspection it can be seen that they are not contradictory, but merely describe a complex situation at different levels. What unites these further studies is that they agree that the body of evidence as a whole would appear less divided and confusing if effectiveness studies were more comprehensive and thorough in their description of the various tasks examined as well as the representation, data type and strategy that may be adopted. Any investigation into any aspect of representing abstract quantitative data needs to be conducted in the awareness that the results are unlikely to be universal given the wide variety of potential interactions discussed.

2.6 Summary

The purpose of this thesis is to explore the role of visual analogy in information representation. The literature review given in this chapter has therefore set out to provide a background relevant to this purpose. To this end a definition of information visualisation has been provided, and a historical perspective provided. A description of the techniques which information visualisation can make use of has been given, and concrete examples of these provided. The focus of the experimental work in this thesis – multidimensional icons- has then been introduced together with an exposition of their salient role in an investigation of visual analogy in information visualisation.

A theoretical framework, of visual analogy has then been described together with a description of how this can be quasi-quantified along a 'low' to 'high' continuum for a given concept. It has been explained that this will be used as a means of systematically investigating the effects of analogy in the experimental work in the thesis. Perceptual and cognitive factors have been described that interface with analogy in order to provide a description into what is known about how information visualisation, and more specifically multidimensional icons, work.

A summary of empirical evaluations into information visualisation was then provided. The evidence as it is (much of which focuses on graphs) seems to suggest a very mixed picture.

Two conclusions are derived from this: Firstly, that wide range of variables which need to be considered when planning and deriving conclusions from such studies. Secondly, it is proposed that an investigation into the systematic use of visual analogy may be an appropriate method of deigning better representations. Specifically with regard to multidimensional icons, there are a number of areas in which theoretical knowledge is lacking: when to choose certain forms, how to decide on allocation within these forms, also how people relate to these forms. These are all important to an investigation of the role of analogy in multidimensional icons and extrapolating from this, in information visualisation. In the next chapter a proposed methodology is outlined to explore the above questions.

Chapter 3 - METHODOLOGY & STRUCTURE

3.1 Characterising Information Visualisation

As has been demonstrated, the scope of 'information visualisation' and the tasks for which it can be used are extremely wide. The methods through which this can be achieved also vary greatly from advanced techniques such as three dimensional rooms, to more common and low-tech methods such as bar graphs. There is currently however no theoretical background to explain for example when 3D rooms should be used instead of perspective walls, or indeed when city visualisations should be used instead of more abstract bar graphs. Clearly a city visualisation has more scope to include information which is both qualitative as well as quantitative, however it is currently unclear as to exactly how and when this might bring about any advantage if indeed it would bring about any advantage at all.

The applications and methods such as those described in Chapter 2 are by no means a comprehensive list. The intention has been merely to illustrate the range and nature of those which currently exist. The number of applications can therefore be seen to be significant and growing while at the same time there is a lack of theory as to why they work or how they work. This has often been stated to be the case within developing technological fields. A re-current assumption about technological progress is that it is driven by the application of scientific theory. However this is actually in contradiction of the facts (Dowell & Long, 1998; Lansdale, 1996). A more compelling analysis it can be argued is that technology disciplines acquire and develop their own knowledge which enables them to design their own problems. As an industry becomes more established, ad hoc innovation is supplanted by more methodical practices through which the experience of prior problems is codified and re-used.

The same argument can be applied to the activity of designing cognitive tools. The nature and variability of human tasks and artefacts means that the role of scientific theory as a prescriber of the 'true' way to design is unrealistic. Rather the aim should be more one of matching in as close and effective a way as possible, human cognitive abilities to human cognitive tasks. As such therefore the aim of this research is to extend the picture of what aspects of information visualisation might be effective in this context

Taken as a subset of cognitive design, the current state of visualisation can be seen to be in the embryonic stages of a technical discipline as described by Landes (1969) in that the current crop of new methods and manners of showing information are largely the result of 'inspired tinkering'. Lohse et al. (1994) also describe the current state of visualisation as a "grab bag of techniques". Novel ideas and manners of displaying information, aided by the ever growing power of computer hardware mean that alternative forms of visualisations are widespread throughout an eclectic range of applications (Gershon & Eick, 1997). If visualisation is therefore to progress, a satisfactory theoretical support needs to be developed, and the results from previous investigations capitalised upon.

As has been discussed already in this thesis – the lack of a satisfactory theoretical support cannot be directly attributed to a lack of endeavour in this direction. Indeed a large number of studies can be found concerning more simplistic versions of information visualisation such as graphs and object displays. The unfortunate fact (from a theoretical perspective) is simply that information visualisation use in terms of a perceptuo-cognitive system appears to have too many important variables for a neat theory to be formulated which accounts for all the results that have so far been produced. In addition to this it can be assumed that a 'satisfactory theoretical support' would also include a prescriptive element in terms of design. This is also currently far from the case.

3.2 How Should Information Visualisation Be Investigated?

A key question, which needs to be addressed at this point, is how any research can meaningfully address such a diverse area, incorporating so many different facets. To repeat once more the definition of information visualisation given by Card, MacKinlay & Schneiderman (1999), information visualisation is

> "The use of computer-supported , interactive, visual representations of data to amplify cognition"

It is very difficult to distil researchable areas from such broad terms as "computer-supported", "interactive", and "amplify cognition". Any research attempting to address the area as a whole needs out of necessity to limit which exact aspect of the area to focus on – whether it be type of computer-support, the type of interface or the amplifying cognition aspect. This thesis concentrates upon the amplifying cognition aspect of the area –this being the ultimate goal-, and most of the research outlined so far has explored this line.

What is the process involved in amplifying cognition involve however? Card, Mackinlay & Schneiderman (1999) define this is in the context of information visualisation as being a process of knowledge crystallisation. They describe this as a 5 stage process consisting of foraging for data, searching for schema, instantiating the schema, Problem Solving and decision making based on the outcome of the problem solving.

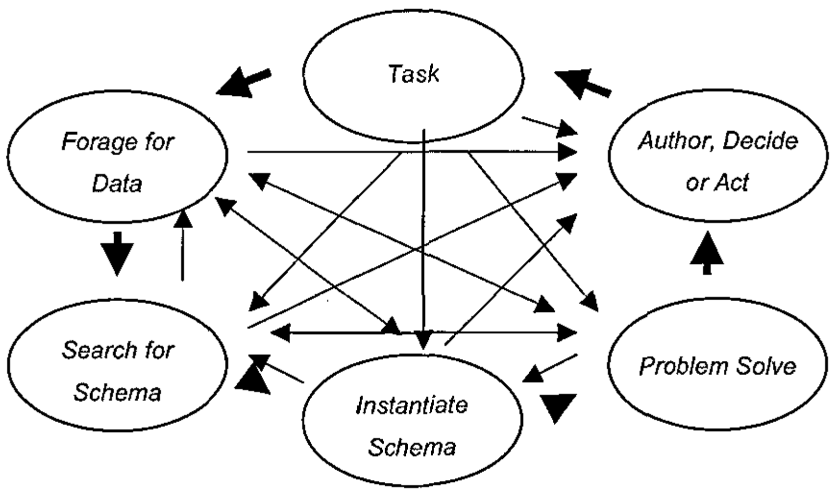


Figure 3-1 Knowledge Crystallization (taken from Card et al., 1999)

This thesis aims to investigate the role of visual analogy in information visualisation. A convenient way to do this is to develop a set of representations which differ in analogy and investigate systematically varying effects which they are able to cause. This is the method adopted throughout this thesis and as such, with regard to the table above – the data has already been foraged, and a schema found and instantiated (i.e. the data has been found and represented in a pre-defined schema). As such the thesis will concern the problem solving aspect, and the decision resulting from the process in a variety of different settings.

Within this sub-area of amplifying cognition, the problem of producing meaningful and robust findings still exists. This is witnessed by a large proportion of research looking at representation type which was outlined in Chapter 2. The results considered in isolation may well be meaningful, but have largely lacked coherence of direction, and when considered as a body of literature, have not lead to an increased understanding (other than that the area is extremely complex). One aim of this thesis is to attempt to overcome this problem and advance understanding of the area such that applications can be designed on the basis of this information in a more informed manner. As such the research has an ergonomic agenda in that it falls under the definition of

> "that branch of science and technology that includes what is known and theorized about human behaviour and biological characteristics that can be validly applied to the specification, design, evaluation, operation and maintenance of products and systems to enhance safe, effective and satisfying use by individuals groups and organisations" (Christensen et al., 1988).

This thesis will focus on the issue of human performance across a strictly defined range of representations. As has been demonstrated, the number of applications being produced is increasing in tandem with the diversity of these applications. In answer to the question posed by Foley (Talbert, 1997) "Is it that we don't know what makes effective visualisation ?", the response given in this thesis will be a qualified "No" – this being witnessed by the disarray in the most relevant evaluation literature. The qualifications appended to this answer however lie in the fact that a great amount is now known about the workings of the human mind. The problem however is that many of these findings have not been applied to areas which would usefully benefit from them. Considered in totality there is a lot known about what makes effective visualisation. If this knowledge were appropriately applied, it could be argued that the literature in the area would be more coherent. One of the most valid ways to address this is through a human-performance driven perspective within the confines of a specific application.

The approach adopted in this thesis therefore will be to focus on a subset of information visualisation –multidimensional icons- and to try and develop a more specific link between theory –in this case that of visual analogy- and practical design –i.e. how a knowledge of visual analogy can help make decisions on which icons to choose and how to configure them-. This will be done within a subset of the overall process – namely the data and a number of different schemas (at various levels of analogy) to represent it has already been decided upon and presented to the user. As different types of information visualisation (e.g. cone trees or perspective walls) use analogy to different degrees, it is argued that this knowledge will be potentially relevant to a wide range of information visualisation types in addition to multidimensional icons.

3.3 Potential Empirical Methods

Information Visualisation places a number of constraints on the choice of method that can be used as there is little existing theory specific to information visualisation which can inform design. As has been discussed, this is something that tends to grow in tandem with the number of applications produced. There is however currently a need for more theoretical knowledge. The area is also extremely diverse, meaning that any theories that are produced should ideally be applicable across these varied domains. A number of constraints are more pragmatic. The first is that information visualisation applications incorporating a significant interaction element are still not common - finding information visualisation applications *in situ* is therefore not an easy task. A further practical consideration from the point of view of PhD research is a matter of resources in terms of both time, money and the accessibility of participants willing to contribute. The sum of these constraints serves to narrow the choice of potential research methods which could practically be used. Galliers (1992) has outlined a number of scientific methods which are particularly relevant to information systems research. These include:

- Field Experiments
- Case studies
- Simulations
- Surveys
- Laboratory Experiments

3.3.1 Field Experiments

Field experiments require the subject of investigation to be examined *in vivo*. They are therefore a very useful approach when validity in real world settings is important. Indeed examining systems in real life is the only way many important factors can be realised and truly appreciated The disadvantages of the field experiment however are that they can give rise to the Hawthorn effect where participants behave in a different manner than normal as they are aware they are being observed. This can be more troublesome in field experiments as they do assume a greater degree of ecological validity than laboratory experiments. They also typically require a greater degree of assent as organisational consent is usually required.

Field experiments may have been an appropriate method in the context of an investigation into multidimensional icons, however there were a number of practical reasons why this was not the case in this instance. Firstly it would have required the identification of a suitable setting where use could have been observed. As has been mentioned already, this would have been difficult to find. Another reason is the fact that any study would have required a suitable visual representation to be devised and used. One of the key factors behind this research is that there is little theoretical basis on which to devise such an application. A field experiment may therefore have been an appropriate companion to more fundamental laboratory research, however the pragmatics of time and accessibility have precluded its use here.

3.3.2 Case Studies

Case studies involve the detailed description of a particular scenario where a problem is usually followed through to a solution. As such they are a useful way to learn or communicate in depth about detailed aspects of a specific situation, but require an analysis of a problem and a solution. In the context of this thesis they are not a particularly appropriate research method to use as the aim is to generate general theoretical output., which can be used as a partial basis to generate future 'solutions'.

3.3.3 Simulation

Simulations can be described as 'dry runs' of particular processes, scenarios or products. Typically simulations involve reduced functionality although this is not always the case. The 'Wizard of Oz' technique is a classic example of the benefits of simulation, where computer applications can be tested –the difference being that a human and not the computer is carrying out the commands or generating the output. Simulations are a cheap method of isolating problems or issues before the expense of implementing the application or procedure is undertaken.

The concept of a simulation is useful for the purposes of research here. While the intent is not to produce a fully working product, the model of a working product is useful for the purposes of experimentation. While therefore a strict simulation will not be used, the idea of a simulation will be "borrowed".

3.3.4 Surveys

Surveys involve obtaining the opinions of participants and can be administered on the spot or left for participants to complete at their convenience. As such they are an extremely efficient and cost-effective way of obtaining a large amount of data on a wide range of issues providing participation can be encouraged. They do however only collect opinions of participants and so the value of this needs to be carefully assessed depending on the situation.

Surveys are a good initial technique to enable issues of interest to be identified and subsequently focussed upon. Their relative ease with which they can be administered in order to collect a wide range of subjective data mean that they are a worthwhile method to employ. In the context of information visualisation, there is definitely a use for subjective data, in concert with the collection of objective data. The survey will therefore be used as a companion technique in this thesis.

3.3.5 Laboratory Experiments

Laboratory experiments are a staple of cognitive psychological research as they are an extremely powerful way of isolating effects providing they are designed correctly. Their power lies in the fact that they can be designed with a specific measurement in mind, and reveal it without the confounding effects of other unwanted factors playing a part. The disadvantages of experiments are that they place somewhat unnatural demands on the participants, who are most often aware that they are being measured in some way. While robust and reliable effects can therefore be uncovered, the validity of these findings in the real world can not always be left unquestioned.

The vast majority of studies mentioned in the literature have been experimental studies. Given that the aim of this thesis is to produce theoretical knowledge in the field of multidimensional icons which can be applied across information visualisation domains, then the experimental approach is highly valid.

Choice Reaction Time

Within the experimental paradigm chosen, the particular type of experiment which will be employed will be that which make use of Choice Reaction Time.

Measurement of reaction time is one of the most commonly used methods within the discipline of cognitive psychology. The term 'Choice Reaction Time' (CRT) refers to the time taken to make an appropriate response to one of a number of signals, when the total possible set of signals and their responses have been experimentally predetermined. The first study on CRT was carried out in 1868 by Donders, and has been expanded upon ever since. Examples of CRT use in a variety of disciplines are numerous and include such diverse areas as: the effect of different altitudes on the CRT of international rugby players (O'Carroll, 1997), to the effects of alpha-2 agonist medetomidine in a visual choice reaction time in monkeys (Rama et al.,1997).

Smith (1968) categorises work carried out on influential factors on CRT into the following categories:

- number of alternatives
- stimulus probability
- stimulus value
- repetition of stimulus or response
- practice
- emphasis on speed and accuracy
- stimulus discriminability
- stimulus-response compatibility

The purpose of the study described here is not to investigate CRT per se. The above list, however, gives a broad view of the types of issues that could potentially 'confound' or indeed enhance any theoretical investigation if appropriately controlled (a strong argument for a laboratory based experimental approach).

Given that Choice Reaction Time experiments are relatively easy to administer and are powerful if appropriately designed, they will be used here.

Subjective Measurements

While objective measures such as reaction times are a versatile and powerful way of uncovering various cognitive processes, they only tell part of the story. As Sinclair (1995) points out, objective measures may not be possible due to the extent of the variables being measured. Some types of measurement are also not possible to collect objectively. This may be due to the nature of the information or the fact that the participants have a different view of the task in question than the person doing the measuring.

Experts are likely to have a deeper more complex and subtle understanding of a system they are used to dealing with than an observer. Conversely in an experimental context, it may be the case that the experimenter has a deeper, perhaps more effective understanding of how it can be cognitively performed. The strategies arising from this understanding however may not be used by the people taking part – who may have less or perhaps even more effective strategies of dealing with the task with which they are faced. These are difficult to tease out objectively.

Accuracy limits are a further reason as to the potential inadequacy of objective measures. While computers and other instruments are most often more reliable, precise and accurate than humans, this is not always the case where qualitative judgements or multivariate measurements are required.

The final point made by Sinclair is that of validity. There may be nothing wrong with a particular method used, but the incorporation of an additional independent method leads to 'convergent validity' where it is possible to be more certain that the measurements are valid.

The use of subjective measurements here addresses a number of the points outlined above, especially as there are limits to the conclusions which can be made from Choice Reaction Times. Specifically here, an attempt will be made to understand what people think of different representations before and after use, something that is simply impossible to measure objectively. Through collecting such information and asking people about their experiences it is also hoped that a clearer picture can be built-up of how people actually use the representations and what aspects about them are found to be helpful or unhelpful. Finally there is the question of 'convergent validity'. The use of two independent methods should ideally mean they validate each other.

3.4 Results Sought

Having established the methods that are going to be used – What is it hoped that such an examination will be able to show? It has after all been demonstrated in the literature that there is a disarray in the literature as to which display formats are most effective. It has also been proposed that there are a large number of interacting factors which combine depending on the exact task and situation at hand to provide these diverse results. Given these facts, a finding for example that representations with a high degree of analogy are useful for identification tasks, is one which may well not be valid across a number of different scenarios. The aim here is not therefore not to focus on the benefits of multidimensional icons per se, but rather to focus on whether visual analogy can aid the effectiveness of such representations in a limited task domain, and if so, to examine the aspects of both the task and the representation that contribute to this increased effectiveness.

From this, it is hoped to provide findings which are to some extent applicable outside of the tasks and representations here and which hold some degree of validity for any representation where abstract data is portrayed by a representation of an entity or entities invoking a particular meaning in the absence of established reading conventions. This is not a modest aim, and any such proposals must be viewed in the light of the wide range of confounding variables and interactions already described in the literature review. The nature of any such claims are also likely to be fairly limited in scope, however given the current state of understanding regarding information visualisation, it is felt that this is a worthwhile aim.

3.5 Methods Conclusion

This chapter has outlined a number of potential research methods which are of relevance to a study of multidimensional icons given the current state of research in the area. The benefits and drawbacks of these methods have been discussed, leading to an explanation of why an experimental approach was adopted.

More specifically, the type of experiment to be carried out will focus on the use of Choice Reaction Time within the context of a variety of sorting tasks. To accompany the Reaction Time paradigm adopted, subjective measures will also be used. A questionnaire therefore also forms one part of the research. As was also mentioned earlier, the model of a simulation will also be used in some of the experiments.

Chapter 4 - EXPERIMENT 1

4.1 Introduction

The first experiment of the thesis has two aims, one practical and one theoretical. These are as follows:

- To establish empirically, a continuum of analogy of representation type to the underlying concept used
- To establish the mapping between the concept to be represented and the elements within the three different icon types which will be used throughout the course of the thesis

In order to explain the experimental design with regard to the above aims, the concept to be represented and the icons will now be introduced and explained

4.1.1 The concept

The concept to be used here and throughout all experiments in the thesis is the concept of financial shares for specific companies. This domain has been chosen specifically for the reason that it is abstract and has no real world object which can easily be used to represent it. Three aspects of financial shares will be used as the variables which require mapping on the various icons. These are:

Value: This refers to the current price of shares for a given company. Company share prices continually rise and fall for a wide variety of reasons. 'Value' as it is referred to here represents the current price of the company featured in the icon.

Availability: Any one company has a finite number of shares. A different proportion of these shares will be available for sale at any one time. 'Availability' as it is referred to here refers to the proportion of shares which are available to be bought for the company shown in the icon at that specific time.

Package Size: Different companies are structured such that different numbers of shares are required to be bought together in one 'package' whenever a transaction takes place. The size of these packages is always the same for a given company. 'Package-Size' as it is referred to here describes, in relative terms, the size of these packages for the company featured in the icon.

These three concept variables relate to individual shares in different ways, and this was an important reason why they were chosen. 'Value' is an integral aspect of any one individual share. 'Package-Size' on the other hand is a variable which refers not to an individual share but rather to defined groups of shares, describing the size of these local groups. 'Availability' is then a more global variable which describes the totality of all shares for any one company. Availability is a proportional value. It can therefore at its maximum refer to "all of" or at its minimum to "none of".

These three variables are therefore qualitatively different from each other. This presented the opportunity for any icon used to represent them to show these differences more or less clearly. The icon types chosen were chosen purposely for this reason. Of the three types, one was chosen as it was felt to represent this relationship very well, the second – not as well, and the third not at all.

All three concept variables (Value, Availability, Package-Size) varied in quantity. For the purposes of this experiment and all subsequent experiments, this was restricted to 'High', 'Medium' and 'Low'. There were a number of reasons for this. Most importantly, the ability with which quantitative differences can be detected cannot be assumed to be equal between brightness and height for example. As perceptual discriminability was not an issue under investigation, the different levels which participants were required to detect were designed to be made as clearly distinguishable as possible. Restricting the level of variance to three discrete levels, was a primary way of achieving this. In addition the restriction of variance made design of the icons and the experiments far simpler.

4.1.2 The Icon Types

Three different icon types were used (See Figure 4-1 & Figure 4-2,3,4). As stated these were generated specifically because they were felt to visually describe the nature of the different concept variables (i.e. Value, Availability & Package-Size) with different degrees of effectiveness. In other words they were felt to differ in terms of how analogous they were to the underlying share concept. As no systematic way of arriving 'a priori' at an optimum icon choice currently exists, the choice of icon design was made informally. There were however a number of systematic reasons why, they were felt to differ in terms of analogy which can be grounded in Gattis's (2001) theory of visual analogy. The various icon types used will now be described together with a more precise justification as to why they were chosen.

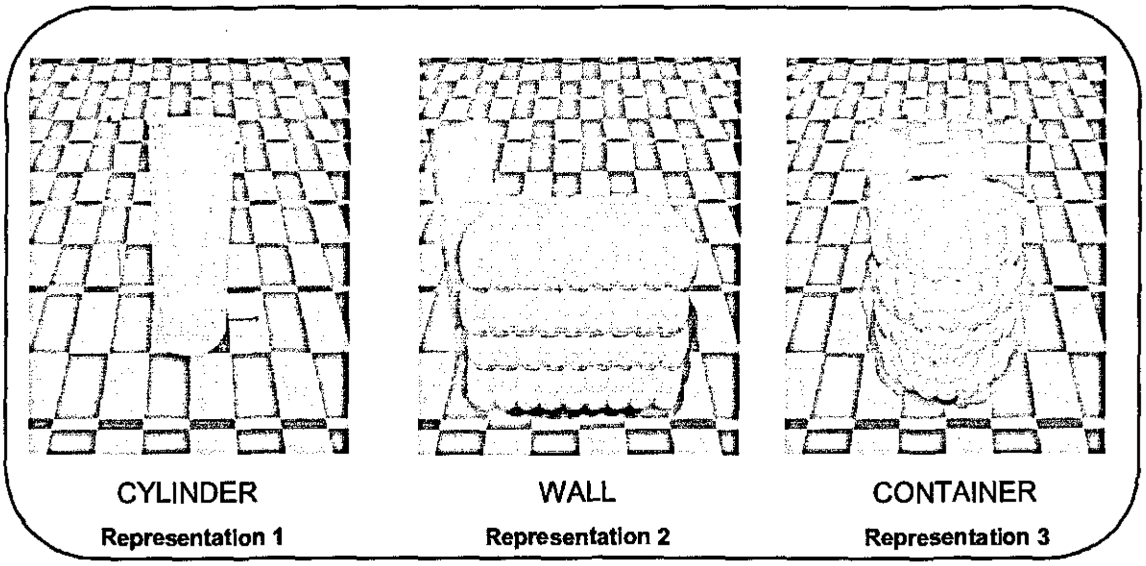


Figure 4-1:Representations Used In Experiment 1

CYLINDER

The cylinder was hypothesised to be the least descriptive representation. It allowed quantity to be represented by featuring different levels of height, diameter and shading, and showed the fact that the variables were related to each other.

In terms of Gattis's (2001) theoretical description of visual analogy: ***Iconicity*** was not an issue here as it is not possible to resemble a financial share. ***Polarity*** was also not an issue as the direction of mapping was not pre-set. In this icon type it was felt that no ***Associations*** existed between shares and the pink cylinder. In terms of ***Structural Similarity***, One object (the cylinder) was used to describe all objects in the concept (packages, company, shares), so object pairing was not coherent. Relationship mapping was designed to be coherent in the sense that change in the level of icon elements (e.g. small, medium, large) was designed to map to change in the level of conceptual variables (e.g. low value, medium value, high value). Higher order relations were not coherent in this icon. This means that the relationship structure of the financial shares concept as described did not equate to the relationship between height, diameter and shading in the context of a cylinder.

WALL

The wall icon was hypothesised to be the second most suitable representation. This was a more complex icon consisting of a stack of balls piled next to a glass wall. The variable elements in the icon consisted of the size of the balls, their height against the glass wall, as well as the metal they were made of. The wall was included in the representation in order to provide a benchmark against which the height could be compared. As such the wall served a similar purpose as the vertical axis in a Cartesian graph.

In visual analogy terms, ***Iconicity*** and ***Polarity*** were again not an issue. There were a number of potential ***Associations*** present in this icon however which were not present in the cylinder icon. First of all the colour of the metal balls was more specific than the arbitrary shading used in the first representation as the types of metal used were gold, silver & bronze. These metals all have a value hierarchy associated with them – as embodied in medals which are awarded for 1^{st}, 2^{nd} & 3^{rd} positions in competitions such as the Olympics. There was therefore a potential association here with value. The balls themselves appeared as integral units and hence this shared some associations with Packages, these concept variables also being integral units. In terms of ***Structural Similarity***, relation mapping, as in the cylinder icon, was designed to be coherent. Object mapping was more coherent in this icon type than the cylinder icon in the sense that many objects (balls) were used as a potential mapping for the many conceptual objects (packages), although Individual shares were still not represented. In terms of higher order relations, the wall icon was more coherent as the concept of local groups of packages was explicitly represented. This idea of size of packages and number of packages could therefore be differentiated, something which was not possible in the cylinder icon.

CONTAINER

The Cylinder icon was felt to be the most suitable of the three icon types featured. This incorporated all the variables of the wall icon with the difference that the glass wall encircled the ball stack to completely enclose it. As such the appearance became that of a container inside which the balls were present.

In terms of Visual Analogy theory, the same applies for the container as for the wall icon, with one difference. The concept of a container provided a clearer ***Association*** with the concept variable 'Availability' as a complete company (with 100% shares) could be represented by a full container with 100% of its contents present. An incomplete company (with 33% or 66% of shares available) could then be represented by a container which was partially empty to varying degrees. In this sense the Structural Similarity of this icon was different to the wall icon in the sense that a higher order relation of "all of" (a full container) and "none of" an empty container was more explicitly present than in the wall icon.

4.1.3 Allocating Mappings

This experiment therefore involved a concept and three icon types which were felt to express the concept with varying degrees of success. It was not clear however, if these meanings would be intuitively clear to users. This experiment set out to determine this, by first explaining the concept to participants, and then asking them to map the concept elements (i.e. value, availability, package-size) to the icon elements. They would be required to do this by sorting out a pile of all possible combinations for one icon type (3x3x3=27 cards) three times, once for Value, once for Availability and once for Package-Size. For each of the three times, participants would be required to separate the cards into high, medium and low levels, and then to explain their rationale. A sorting task has been used here as it provides a practical way of observing natural mappings which involve participants having to act out their decisions. This method should therefore both allow an idea of how users would freely allocate the mappings, as well as ensuring there is some degree of reliability behind these choices as they are then required to act upon their decisions. An unwise choice could therefore be changed on gaining experience with the implications of it. This would not be possible if a choice was made by questionnaire for example.

As there were a specific number of ways in which the icons were felt to differ in suitability for the concept it could be expected that participants would be able to use this suitability to help them make their mapping decision. This would be in accordance with what Visual Analogy is theorised to do, namely constrain mappings (Gattis 2001). An investigation into whether this is true forms the theoretical aim of this experiment.

The act of requiring regular users to allocate mappings according to their own free choice is also useful for later experiments, in that the most natural mapping for each icon type can be empirically identified. An investigation into what the mappings should be in subsequent experiments therefore forms the practical aim of this experiment.

As it cannot be guaranteed that participants will not see some other unanticipated aspect of the icons and map according to this (e.g. shininess) – participants will first be asked to sort freely, and then 'forced' to sort according to the three variables intended (e.g. height, diameter and shading in the case of the cylinder). This will ensure that information can be obtained which can be used to choose the mapping for subsequent experiments.

4.2 Method

EXPERIMENT 1

4.2.1 Participants

54 participants (29m:25f) volunteered to take part in the experiment, all of whom were students at Loughborough University, had no significant experience with share dealing, and possessed normal colour vision. Ages ranged from 18-29. Participants were randomly assigned to one of three between-subject groups.

4.2.2 Representations

The representations already described were rendered using the POVRAY™ ray tracing program on a Apple Power Macintosh 4400/200 platform. POVRAY™ is a highly flexible, freely available programme which offers virtually unlimited representation possibilities in three dimensions. Lighting, object shape, object material, viewpoint and background can all be independently specified allowing every aspect of the representation to be precisely specified. This specification is carried out in 'scene description language' derived from C+ (Appendix 5-1, 5-2, 5-3).

In the first representation a cylinder was specified which was one of three heights (2.75cm, 1.83cm & 0.92cm), one of three diameters (1.6cm, 0.85cm & 0.3cm), and one of three shades of Neon-pink. Neon-pink was chosen as a colour as there was a large degree of difference between its lightest extreme (fluorescent) and darkest extreme (dark grey/pink). At the same time however there is no particular value judgement associated with shades of pink. Two measuring rods of tinted glass, which measured out the maximum dimensions that each cylinder could possibly be were also incorporated into the design. This provided an absolute comparison, so that any one cylinder could always be compared using the same 'maximum' criteria. As such the same number of pictorial cues were provided in every representation type

In the second and third representations, the balls themselves were specified to have radii either of 0.2mm, 0.4mm or 0.6mm. Regardless of diameter, the stack of balls would always reach one of three heights, identical to the cylinder heights in the first representation: (0.92cm, 1.83cm, 2.75cm). Finally, the balls were specified to appear like Gold, Silver or Bronze metal. In total there were 3x3x3=27 possible combinations of each of these, all of which were rendered. In the 'wall' representation (Representation 2 in Experiment 1) the glass wall was comprised of a darkened glass rectangle positioned to fit against the left hand edge of the stack from the viewpoint of the user. In the 'container' representation (Representation 3) the shape of the stack was altered to ensure that the balls would all fit inside the circumference of the container. In all the representations, the viewpoint adopted was slightly elevated from the representation. This allowed for an adequate view of the boundaries of the cylinders and ball stacks.

The background to both the container and wall icons was a chequered blue and white floor which extended towards the horizon. The purpose of this was to provide an additional method of height comparison, as different height stacks covered different numbers of squares. The colour of the floor also contrasted with the balls therefore aiding the visual clarity of the representation.

In this experiment all representations were printed on a colour laser printer and mounted on laminated cards of size 11.5cm x 9.5cm.

4.2.3 Procedure

Participants were first screened to ensure that they had no experience of share dealing, and possessed no visual conditions which may influence their ability to complete the task (Appendix 5-4). Each participant was then educated (Appendix 5-5) in the rules of Financia - a fictitious stock market which required shares to be described in terms of Share price, Availability and Package-Size. Once it was indicated that the concepts were understood, participants were then asked to complete a written multiple choice test (Appendix 5-6) on the meaning of the variables in order to prove that they did actually understand the concepts. On completing all questions satisfactorily, they were then assigned to one representation type (Cylinder, Wall or Container).

The 27 potential combinations of representation were laid out on individual cards in front of each subject, and they were then asked to sort all 27 representations in terms of one of the three variables (Value, Availability or Package-Size) according to whether it was 'High', 'Medium' or 'Low'. No rules were given as to how these were represented. Once this had been done, participants were asked to give their rationale for sorting and this was noted.

If participants sorted the representations in terms of an unintended feature, or chose one visual variable more than once, then they were subsequently prompted to sort according to the intended variables (E.g. Metal Type, Height & Ball Size) in a 'forced' condition and the results again noted. The 27 cards were then spread out again and the procedure repeated for the remaining unsorted representation types until a sorting rational had been obtained for each variable. The order in which this was done was rotated to prevent any order effects.

4.3 Results

The results were classified into two sets of tables: 'Unforced' choice where participants had sorted the representations completely freely (i.e. In some cases according to emergent features) and 'Forced' choice, where participants had been required to sort the cards in terms of the visual variables intended. (i.e. Ball Size, Height, Metal Type). There were two purposes of having two sorting regimes. Firstly, the unforced choice allowed an unbiased picture to be collected of what the representations initially meant to people, without the expectations of the experimenter. Secondly, the 'forced' choice sorting regime allowed a decision to be made of which concepts (i.e. Value, Availability, Package-Size) should be mapped to which pictorial variables (e.g. Ball Size, Metal Type, Stack Height) in future experiments.

Counts were taken of the number of times participants had assigned each visual variable to each concept variable. A Chi-Square analysis was then performed for each representation to reveal if there had been a significant difference in allocation preference

4.3.1 Unforced Choice

Representation 1 (Cylinder)

	Colour	Height	Diameter	Volume	χ^2 (d.f.)
Value	4	10	4	0	(3)**
Availability	3	7	6	2	(3)
P-Size	3	2	8	5	(3)

Table 4-1: Number of Times Concept Variable Allocated to Visual Variables in Cylinder Condition

Representation 2 (Wall)

	Metal	Height	Ball-Size	Stack Volume	Number of Balls	Ball Number / Height	χ^2 (d.f.)
Value	4	7	3	1	2	0	(5)
Availability	0	11	2	1	4	0	(5)**
P-Size	0	5	7	1	5	1	(5)*

Table 4-2:Number of Times Concept Variable Allocated to Visual Variables in Wall Condition

Representation 3 (Container)

	Metal	Height	Ball-Size	Number of Balls	Colour/Height	Colour/Size	χ^2 (d.f.)
Value	9	7	0	2	0	0	(5)**
Availability	2	9	4	1	1	1	(5)**
P-Size	1	4	12	1	0	0	(5)**

Table 4-3:Number of Times Concept Variable Allocated to Visual Variables in Container Condition

A number of features are immediately visible. Firstly there are fewer unintended 'emergent features' present in the cylinder condition (Representation 1). This is perhaps not surprising given the fact that the other two representations are more complex. In terms of Chi-Square values, the cylinder condition is clearly the most ambiguous of the three representations in terms of meaning. Only one of the pictorial variables in this representation (Height) is consistently mapped to a *particular concept* (*Value*).

The manner in which the concepts are mapped to visual elements in the other two representations show a more defined pattern. In the wall condition two of the three concepts are mapped significantly more to a particular visual element (Availability = Height; Package Size = Ball Size), while in the Container representation (anticipated as being the most specific) all three of the concepts have been mapped to a particular visual element (Value = Metal Type; Availability = Height; Package Size = Ball Size). This is as predicted.

The 'Unforced' choice section of the study has therefore confirmed the initial expectations of the experiment. These were that the more specific 'Container' representation would show a clearer choice pattern and that the pictorial variables and concepts would be paired together in the manner chosen. Some participants however mapped certain concepts to unanticipated emergent features (E.g. Number of Balls). The next part of the study therefore removed the possibility of this being allowed to occur, forcing participants to choose from the three anticipated visual elements only (E.g. Metal Type, Ball Size & Stack Height):

4.3.2 Forced Choice

The results in the forced choice condition are a combination of the results from participants who sorted 'correctly' without being prompted, and the results from participants who had sorted in an 'unanticipated' manner the first time around and were forced to sort again in terms of the anticipated variables, choosing each only once.

	Metal / Colour	Height	Ball Size / Diameter	ϰSquare Significance
CYLINDER				
Value	6	8	4	(2)
Availability	6	6	6	(2)
P-Size	6	4	8	(2)
WALL				
Value	15	1	2	(2)**
Availability	1	14	3	(2)**
P-Size	2	3	13	(2)**
CONTAINER				
Value	12	6	0	(2)**
Availability	6	12	0	(2)**
P-Size	0	0	18	(2)**

Table 4-4: Number of Times Concept Variable Allocated to Relevant Visual Variables When Constrained

When participants are constrained in their choice the situation is slightly different. Again it is clear to see that the Cylinder condition has the least agreement with regard to what the visual elements are thought to mean. None of the Chi Square values are significant in this condition. In the case of the Cylinder and Wall representations, all Chi Square values are significant- and the sorting preference also matches the anticipated mappings.

One interesting point to note is that there was little disagreement with regard to the mapping direction. That is, in all cases large size equated to large concept value. This is in accordance with the literature in this area. The situation with metal type mapping was slightly different with 7 of the 36 participants dealing with metal type according to 'dullness', 'brightness' or in an arbitrary manner. On being questioned on their reasons for this the majority of these participants had simply forgotten that the colour difference should equate to 'Gold', 'Silver' or 'Bronze'. The participants that did recognise the metal distinction appeared simply not to associate it with the value scale of 1st, 2nd and 3rd. In the cylinder condition 14 of the 18 subjects sorted accorded to brightness – a clear majority but not an overwhelming consensus The potential implications of this mapping are discussed in section 5.2.6.

4.3.3 Conclusion

To conclude then, Figures 4-2, 4-3, 4-4 show the mappings which will be used in the subsequent studies in this thesis:

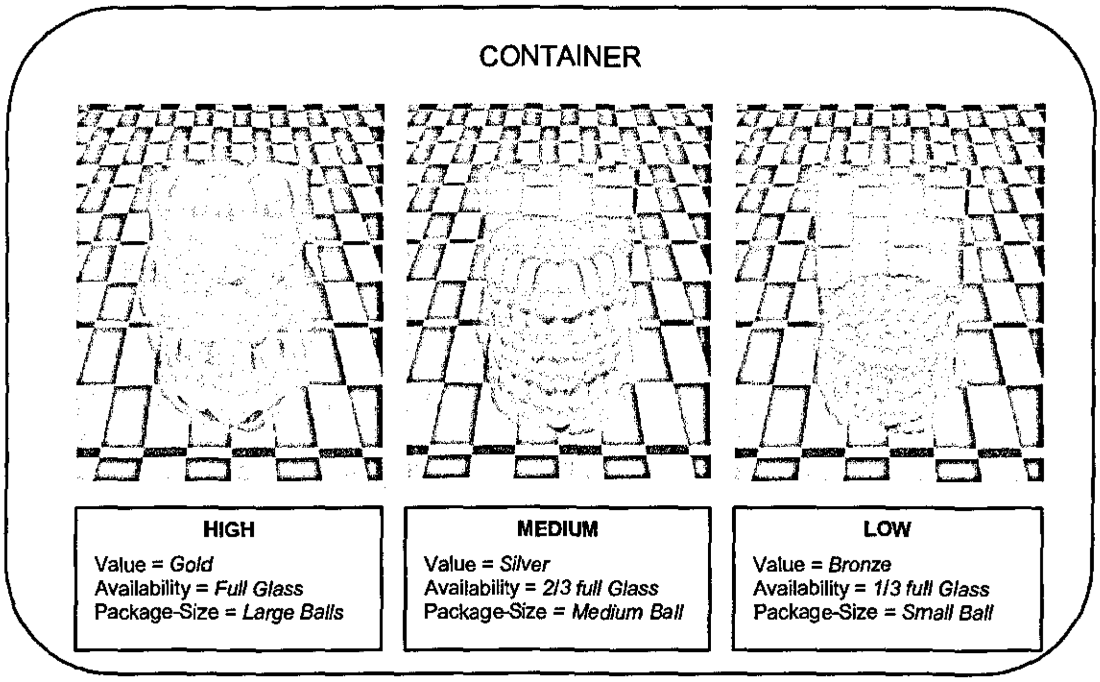


Figure 4-2: Key To Representations Used In Container Condition

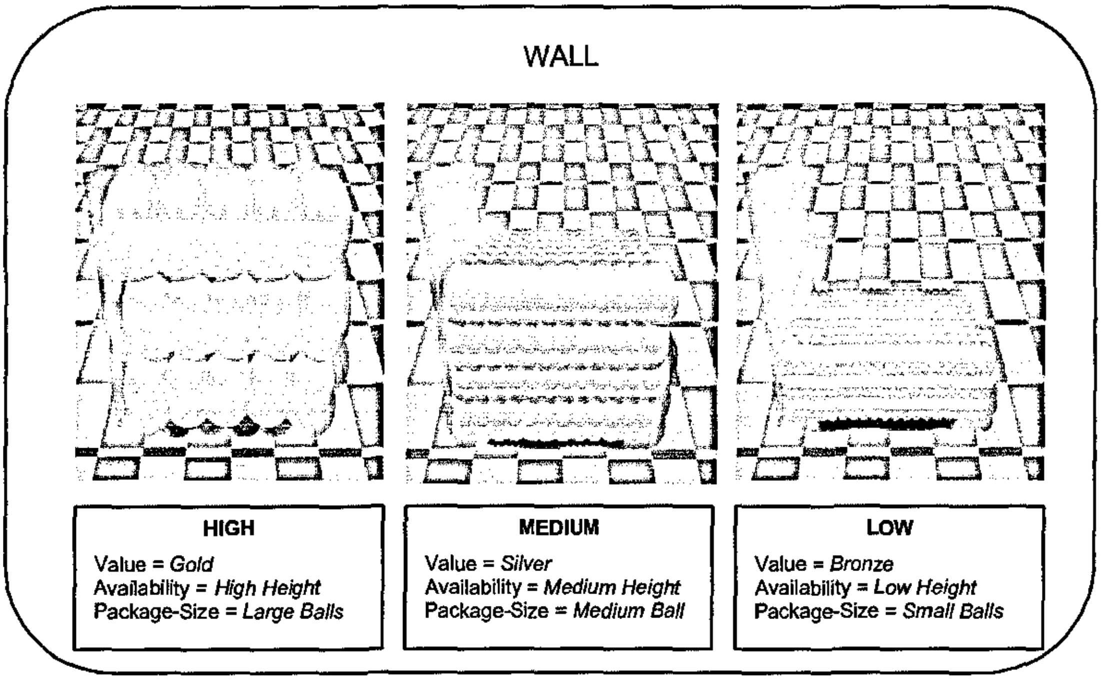


Figure 4-3: Key To Representations Used In Wall Condition

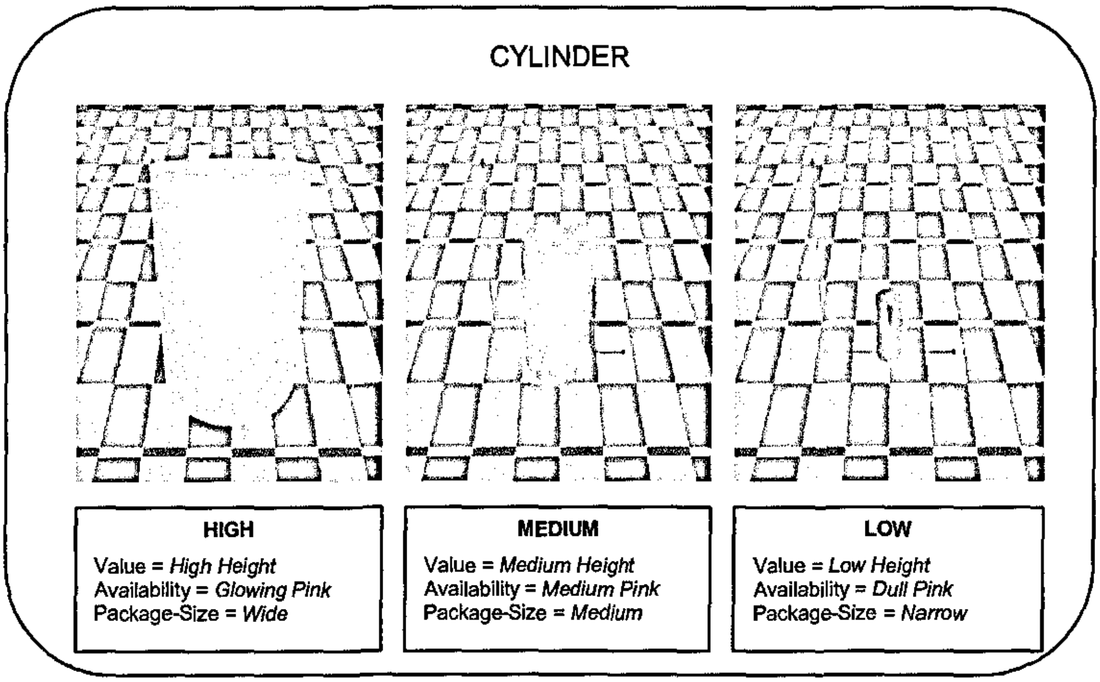


Figure 4-4: Key To Representations Used In Cylinder Condition

4.4 Discussion

As stated earlier the purpose of this study was twofold:

- To investigate empirically if the different icons have different degrees of 'naturalness' for mapping to the underlying concept used
- To establish the mapping between the concept to be represented and the elements within the three different icon types which will be used throughout the course of the thesis

With regard to the first aim, the experiment has been able to reveal that mappings are more consistently chosen when the icon is more analogous to the underlying concept being represented. The Container condition therefore lead to the greatest amount of agreement as to which icon elements should be mapped to which concept elements with the wall and cylinder conditions coming second and third in this respect.

The results from the Container and wall conditions are similar, but it is interesting to note that two out of three concepts in the wall condition when 'unforced' were mapped to height. A probable reason for this is that the wall representation shares some similarities in appearance with a graph where up universally means more (Gattis & Holyoak, 1996). There was no equivalent change along the x axis, so up =more may have been seen as the most logical choice. In the Container condition however this pattern did not emerge, perhaps because the appearance has changed to the degree that it no longer resembles a graph.

An important issue which became apparent during the study was the concept of directionality, where for example UP/BIG=MORE. Whenever the mapping involved size, then there was a universal agreement as to the direction the mapping should flow. LARGE would therefore always equate to HIGH. However less obvious perhaps is the mapping of BRIGHTER = MORE. In the Cylinder condition this was almost always the case, suggesting that there is an underlying conceptual mechanism governing this mapping. Smith and Sera (1992) on the other hand found the opposite in small children and no consensus in older children, while Gattis (2001) points out that dark and light are not marked and unmarked ends of a continuum, but rather are equal. The different result here may be attributable to the fact that the cylinder appears not just dark and bright, but actively appears to glow. This could then bring with it connotations of a power source (e.g. as in a light bulb), with more energy being required to produce the glow. If this were the case it would explain the reason for such a choice.

It is difficult to conclude whether the 'forced' or 'unforced' approach is most valid. The advantage of the forced part is that only the relevant variables were available to be chosen, and participants therefore had to make a choice out of only these. The disadvantage of this is that participants may have felt forced to make an arbitrary choice through being constrained to chose different variables to the ones they felt were most appropriate. One firm advantage of the unforced condition is that it provides the most natural view of what participants would have ideally chosen, free from the 'hopes' of the experimenter, and in this sense it is probably the more valid of the two approaches for investigating natural mapping allocations. One note of caution should be the suitability of the Chi Square test for the analysis of the 'forced' choice condition. In this part of the experiment, the choices were not strictly independent, one of the pre-requisites of the test. Unfortunately there is no test which is more suitable for data of this nature. Hence the test is used with caution. The experiment would also benefit from being repeated with a greater sample size.

An important point about multidimensional icons is that there are no established conventions as to how they should be read. Consequently, although it was anticipated that users would recognise the systematic variables and use these, this was not always the case. Instead, emergent features such as Ball number or combinations such as Colour & Height were taken and mapped to individual variables. The reason for this may have been that such emergent variables were simply easier to see, and that participants did not sort the cards according to a strategy that made most sense but rather one that was easier to carry out. There is always likely to be a conflict of visibility versus meaning when using multidimensional icons. This means that a process of education is important, as it cannot be assumed that all the systematic variables of interest are obvious to all people.

The approach used here was 'hands-on' in the sense that participants were actually required to manipulate the representations according to their individual understanding. This contrasts with the questionnaire approach adopted by

MacMillan & Tatum (1997) in their visual man-power planning tool, where participants were only required to state their opinion in a questionnaire without using the representations. It must be stated that the concept being represented here is fairly simple with only three variables. Where the number of variables extends into double figures or more, then a questionnaire approach may well be a more convenient methodology.

The fact that some subjects were able to 'forget' that the colouring of the balls equated to 'Gold', 'Silver' & 'Bronze' suggests that realism is important in such a scenario. Certainly as a result of this the need became apparent to make the colouring more metallic and realistic. This was achieved in subsequent experiments by adjusting the object colour properties to make them appear more metallic (Appendix 5-7). In addition some people simply did not realise that the colouring was gold, silver and bronze while others realised this, but nevertheless used their own concept based on a different construct such as shininess. This makes the need apparent to not assume that users will understand the mapping between icon elements and the concept they represent even if they do seem intuitively obvious to designers. A process of education therefore seems to be required before using such representations, a fact which was given particular attention in later studies.

4.5 Summary

To summarise, this first study has clearly allowed a mapping to be generated between the elements featured in the icons and the underlying concept variables. It has also provided evidence for a hierarchy of analogy based on mapping constraint, with the container representation having the highest level of analogy, the wall representation having the second highest level, and the cylinder representation the lowest. Having established that an analogy level exists, this can be used to investigate the cognitive implications of analogy in subsequent experiments. The next experiment will now focus on the 'high' analogy representation to gain a clearer idea of the processes involved in assigning a concept 'meaning' to a multidimensional icon.

Chapter 5 - EXPERIMENTS 2 & 3

5.1 Introduction

The last experiment demonstrated that when analogy is present at a 'high' level in a multidimensional icon, this acts as a *natural constraint* when users are required to map aspects of an underlying concept with the individual elements of this icon. The experiment in this chapter will now seek to examine what the implications are in terms of a cognitive overhead when having to 'think by analogy'.

Any cognitive overhead which exists will require cognitive resources to be devoted to it. This allocation of resources, if present, should hypothetically be able to be demonstrated by requiring people to think in terms of visual analogy for a given task and then comparing performance to when thinking in terms of visual analogy is not required.

This issue is not a minor one to information visualisation. One of the primary processes involved in using analogical representations is that of reading their meaning. Elements within multidimensional icons for example, as well as other types of information visualisation, need to be recognised as being relevant and translated into what they mean before a judgement can be made.

This process of doing this is also unlikely to be without some sort of mental effort, and indeed the Choice Reaction Time Literature accounts directly for the process of translating one symbol into a different meaning or action, calling the process 'symbolic translation'. This has been shown to result in a 'cost' which can be manifested in terms of longer reaction times. (Fitts & Deininger, 1954)

There are different levels of potential translation, depending on the task which the representations are being used for. For example a simple iconic element first of all needs to be recognised in terms of the identity of the variable that it is representing as well as the level of that variable. It is possible that certain tasks such as monitoring the state of a process control plant require no more translation than at this level. The recognition that a certain level is higher or lower than normal can be achieved without knowledge of what it is that level refers to. At a more advanced level, the state of a particular variable could be translated into a different modality. For example, in the representations featured here, once a gold ball is recognised a further translation process is required to verbalise the iconic elements shown within it. At an even more advanced level, another level of translation is required to translate the perceptual features of an iconic representation into an underlying concept. In the case of the representations used here, the translation of a golden ball into "high value" requires a further level of translation, where both the variable and the level need to be recognised

This experiment will aim to investigate the differences in time and accuracy, (which can otherwise be called cost) which the different translation levels involve and investigate the nature of the overhead involved in deriving meaning from multidimensional icons.

The experiment described here will investigate this using three different tasks:

- Translation from graphical representation to graphical description (E.g. matching silver ball to picture of a silver ball)

- Translation from graphical representation to verbal description (E.g. Matching silver ball to verbal description "Silver"

- Translation from graphical representation to 'meaning' (E.g. matching silver ball to the meaning "medium value)

The second two of these tasks could both be termed 'symbolic translation'. The last of these however is of main concern to information visualisation. The examination of allocational cost at these three levels should explain where much of the cost inherent in information visualisation lies – i.e. whether this is due to symbolic translation or the more involved process of translation into a seemingly unrelated concept. This will then provide a deeper understanding of the cognitive cost of employing multidimensional icons and indeed other types of information visualisation where a translation into abstract data is required.

This chapter consists of two parts – Experiment 3 in which the sorting task was simple and Experiment 4 in which the task was more complex. The purpose of conducting the study at two levels of complexity was to investigate the prevalence of any differences that may exist, and whether this was evident in simple circumstances, or only under conditions of increased task load.

5.2 Method

EXPERIMENT 3

5.2.1 Participants

18 (9m, 9f) students volunteered to take part in the experiment, all of whom were students at Loughborough University, had no significant experience with share dealing, and possessed normal colour vision (Appendix 5-4). Ages ranged from 18-29. All Participants took part in all conditions of the experiment in a counterbalanced order.

5.2.2 Task

The task involved sorting each of the 27 'High Analogy' representations into one of three piles according to the level of the particular iconic elements within them. All iconic elements were sorted for, but each was sorted one at a time. The manner in which they were sorted differed according to 4 conditions. In the ***'Picture Description'*** condition, each iconic element (i.e. metal type, height and ball size) was sorted according to a pictorial label of the relevant iconic element. For 'Value' for example, this would have required the representations to be placed into one of three piles according to whether the pile was denoted by a label depicting a set of gold balls, a set of silver balls, or a set of bronze balls. In the ***'Verbal Description'*** condition the task would have been the same, but the labels would feature verbal descriptions instead of pictorial descriptions (in this case, the words – "Gold", "Silver", or "Bronze"). In the ***Concept*** condition, the task would again be the same with the exception that the labels would feature "High Value", "Medium Value" or "Low Value". Finally, a ***Random*** condition was included in order to obtain an idea of how long the sorting condition took in the absence of any decision making.

5.2.3 Stimuli & Apparatus

Representations

27 representations of the 'High Analogy' type (described in Section 5.2.2) were used. These featured all possible combinations (3x3x3) of all variables shown on the card. Each representation was printed in colour and mounted onto separate cards sized 9.5 cm X 11.5 cm.

Sorting Apparatus

3 pieces of A4 sized paper were used onto which the sorting criteria were printed (Font: Times New Roman, Size:48), and onto which the piles of cards were to be placed. The criteria depended upon the experimental condition and are shown in Table 5-1:

Condition	PACKAGE-SIZE	VALUE	AVAILABILITY
Concept	"High", "Medium", "Low"	"High", "Medium", "Low"	"High", " Medium", "Low"
Picture-Iconic element			
Word-Iconic element	"Large". "Medium", "Small"	"Gold", "Silver", "Bronze"	"High", "Medium", "Low"

Table 5-1: Sorting Criteria in Experiment 3 & 4

A typical example of the piles into which a participant may have to sort the cards is shown in Figure 5-1.

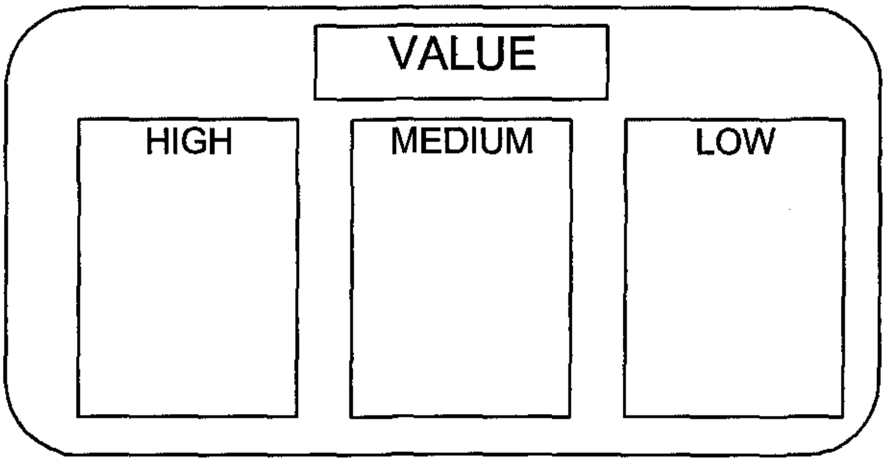


Figure 5-1: Example of Sorting Categories in Experiment 3

5.2.4 Procedure

The experimental procedure can be divided into three stages: The Instruction stage, the Practice Stage and the Experimental Stage from which the results were obtained. These will now be described in order:

Instruction Stage

To start with, each participant was given a printout of instructions relating to the background story of the experiment, as well as exactly what they would be required to do (Appendix 5-5).

The background story given to each participant was that they were helping with the design of a new information display system to show information about company stock market shares. The manner in which the representations varied (i.e. by Ball Size, by Height of the Stack, and by Metal Type) was made clear. It was also explained that each stack of balls represented one company.

The three pieces of information relevant to each task (i.e. Value, Availability, & Package-Size) were also explained together with what these meant when related to a company in the context of the experiment. This was identical to the explanation given in Experiment 1.

To ensure that the meanings of Value, Availability & Package-Size had been properly understood, each participant was then given a multiple choice test (Appendix 5-6) concerning the meanings of the concepts. An example question to test Package-Size for example ran: Company X's shares must be bought in groups of 50 while Company Y's shares must be bought in groups of 200. Which company has the highest Package-Size?" (The answer to the question would be Company Y).

Once it had been established that the meanings of the concepts used in the experiment had been understood, the mappings of concept to analogical representation were explained. These were as established in Experiment 1:

VALUE $\Rightarrow$ Metal Type

AVAILABILITY $\Rightarrow$ Stack Height

PACKAGE-SIZE $\Rightarrow$ Ball Size

Practice Stage

Each Participant was then asked to sort each of the 27 representations (or cards) into 3 piles according to the labels shown above each pile. This involved sorting by:

- ***Random***: Any card could be placed in any pile
- ***Verbal Description***: By verbal labels (E.g. when sorting for Metal Type: "Gold", "Silver" & "Bronze")
- ***Pictorial Description***: As with the Verbal Description condition except that a physical picture of Gold, Silver & Bronze designated each pile
- ***Concept***: The piles were designated by labels of what the representations stood for (E.g. in the case of metal type the three labels featured "High Value", "Medium Value" & "Low Value" respectively).

As the representations differed by Metal Type, Stack Height & Package-Size, a practice sorting run was carried out for each of these aspects. This meant that in total each participant would sort the representations 10 times in the practice session: Once by Random, three times by Metal Type (according to Verbal Description, Pictorial Description and Concept), three times by Stack Height and three times by Ball-Size. The order in which sorting was carried out was rotated systematically between participants to avoid order effects.

It was explained to participants that the task required them to hold the pack of 27 cards upside down, turn each card over one at a time, judge the representation featured on it and then place it upside down again in one of the three labelled piles. It was also explained that a once a card had been sorted its position could not be changed.

Once this stage had been completed satisfactorily, participants then moved on to the Experimental Stage.

Experimental Stage

The procedure followed was identical to the practice session with the exception that participants were asked to complete the task as quickly as possible without making any mistakes. Time and accuracy were recorded for each condition – time being measured between the point of turning over the first card and placing the last card face down.

5.3 Results & Conclusions

The results here describe the time taken to sort the cards as well as the number of mistakes made while doing this.

In the case of Time - this was measured in seconds for each trial. Times for the random condition were subtracted from the other condition times in order to give a measure of decision time alone.

Decision times were then treated as follows:

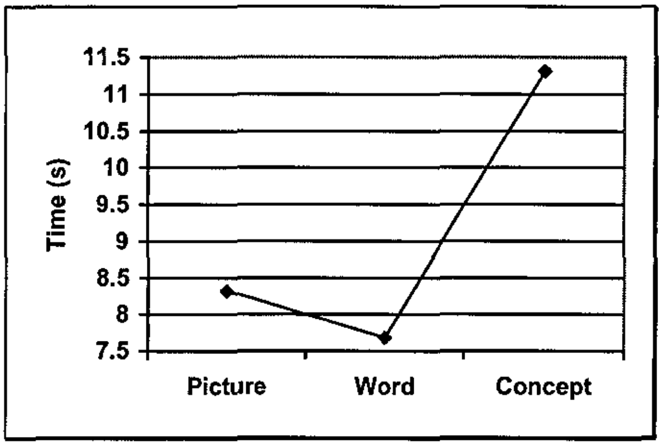
A mean time was obtained of the three times the cards were sorted by picture labels (these three times being when the cards were sorted by height, metal type and ball size). Mean times were also obtained in an identical way for the three times the cards were sorted by verbal description labels, and by concept labels. These three mean times are referred to as the times for each sorting condition.

A mean time was also obtained of the three times the cards were sorted by each iconic elements. This is the inverse of the procedure describe above and involved obtaining the mean of the times when the cards were sorted for metal type, height and ball size by averaging together the times taken to do this for each sorting condition. The three mean times obtained by this procedure are referred to as the times for each iconic element.

5.3.1 Time

Differences Across Sorting Conditions

The mean decision times across all participants for all 27 cards are shown below:



Graph 5-1: Mean Decision Time per Sorting Condition In Experiment 3

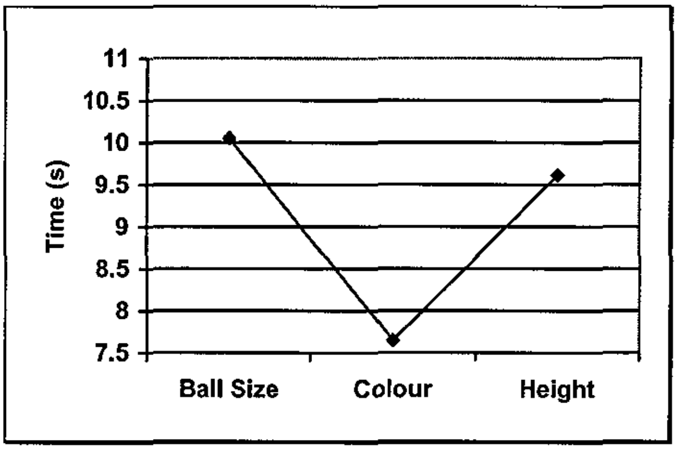
	Count	Mean	Std. Dev	Std. Error
Picture	18	8.317	8.035	1.894
Word	18	7.683	8.971	2.114
Concept	18	11.306	9.709	2.288

Table 5-2: Means Table of Times Across Sorting Conditions In Experiment 3

The exploratory results indicate that the mean decision time in the Concept condition is the longest, followed by the Picture and then the Word condition.

Differences Across Pictorial Variables (Iconic elements)

These have been compared in order to examine if any one Iconic element is particularly difficult to distinguish or sort. The mean decision times for each Iconic element are shown below:



Graph 5-2: Mean Decision Time per Iconic element Condition In Experiment 3

	Count	Mean	Std. Dev	Std. Error
Ball Size	18	10.050	8.286	1.953
Colour	18	7.644	7.877	1.857
Height	18	9.611	10.632	2.506

Table 5-3: Means Table of Times Across Iconic element Conditions In Experiment 3

The initial results show that Colour/Metal Type is the easiest to sort, with Height being the next easiest and Ball Size being the hardest.

Analysis of Variance

A 2 way repeated measures ANOVA was used to determine whether the differences shown above were statistically significant:

Source	df	SSq.	MSq.	F-Value	p-Value
Iconic element	2	59.083	29.541	0.171	0.8440
Subject (Group)	15	2584.114	172.274		
Sorting Condition	2	134.730	67.365	1.763	0.1889
Sorting Condition * Iconic element	4	278.282	69.570	1.820	0.1509
TIME* Subject(Group)	30	1146.561	38.219		

Table 5-4: ANOVA Table of Time Results in Experiment 3

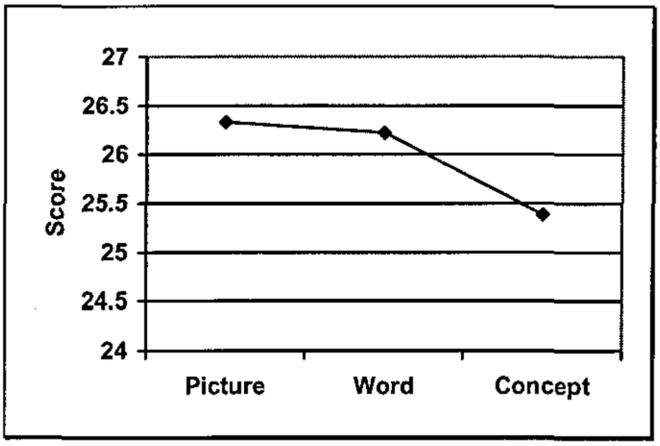
The results revealed that none of the differences were significant. This indicates that there was no additional cognitive cost (in terms of time) of categorising in terms of a concept (E.g. 'High' Value, 'Medium' Value, Low Value) as opposed to when the category was defined in terms of a description (High Height, Medium Height, Low Height).

5.3.2 Accuracy

The number of cards that were correctly sorted was also counted. The results are shown below:

Differences Across Sorting Conditions

The mean scores (max=27) across all participants per condition are shown below:



Graph 5-3: Mean Scores (max=27) Per Sorting Condition in Experiment 3

	Count	Mean	Std. Dev	Std. Error
Picture	18	26.333	1.372	0.323
Word	18	26.222	2.157	0.508
Concept	18	25.389	2.033	0.479

Table 5-5: Means Table of Errors Across Sorting Conditions In Experiment 3

The results indicate that the mean score is highest in the Picture condition followed by the Word condition and lastly the Concept condition. Friedman's Rank Test for *k* correlated samples was used in order to determine if the scores produced across sorting conditions were statistically significant.

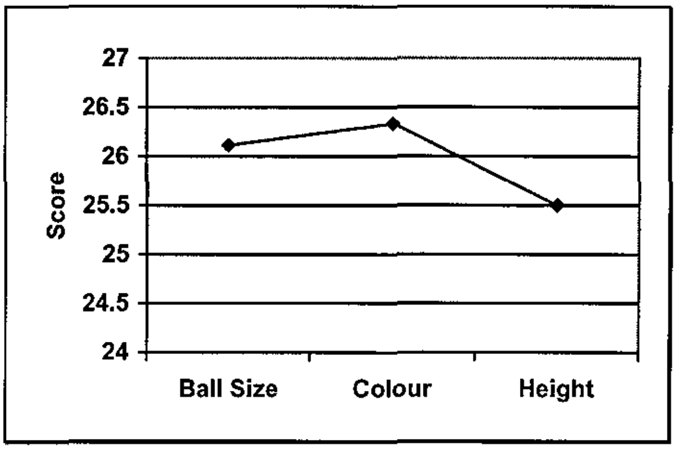
	No. of Groups	Friedman Statistic	p-Value
Sorting Condition Score	3	4.919	0.0855

Table 5-6: Friedman Test Result For Accuracy Across Sorting Conditions in Experiment 3

The result showed that the difference in accuracy is not significant.

Differences Across Iconic element conditions

The numbers of errors made while sorting each Iconic element are shown below:



Graph 5-4: Mean Scores (max=27) Per Iconic element Condition In Experiment 3

	Count	Mean	Std. Dev	Std. Error
Colour	18	26.333	1.372	0.323
Height	18	25.500	2.640	0.622
Ball Size	18	26.111	1.410	0.332

Table 5-7: Means Table of Errors Across Iconic element Conditions In Experiment 3

The exploratory results here indicate that the mean score is highest when the Iconic element being sorted was Colour, followed by Ball Size and then Height. Friedman's Test was also performed to investigate if there was a significant effect of Iconic element on accuracy scores

	Number of Groups	Friedman Statistic	p-Value
Iconic element Condition Score	3	1*351	0.5088

Table 5-8: Friedman Test Result For Accuracy Across Sorting Conditions In Experiment 3

The result here also revealed no significant differences.

Conclusion

It can be concluded from the results in Experiment 3, that there were no significant effects of either sorting condition or Iconic element on decision making time or accuracy.

The results in Experiment 4 then investigate if the equality of decision making time and accuracy across sorting conditions is still maintained with the same task at a greater level of complexity.

5.4 Method

EXPERIMENT 4

5.4.1 Participants

20 (10m, 10f) volunteered to take part in the experiment, all of whom were students at Loughborough University, had no significant experience with share dealing, and possessed normal colour vision. Ages ranged from 18-24. All Participants took part in all conditions of the experiment in a counterbalanced order.

5.4.2 Task

The task in Experiment 4 was identical to that in Experiment 3 except that each card now had to be sorted according to all three variables shown on the card, and not just one as previously.

5.4.3 Stimuli & Apparatus

Representations

These were identical to those used in Experiment 3

Sorting Apparatus

The sorting criteria were exactly the same as in Experiment 3. Experiment 4 differed only in that all elements (e.g. [Value / Availability / Package-Size] or [Metal Type / Height / Ball Size] depending on condition) required sorting at the same time. An example of the sorting categories facing participants in Experiment 4 is shown below.

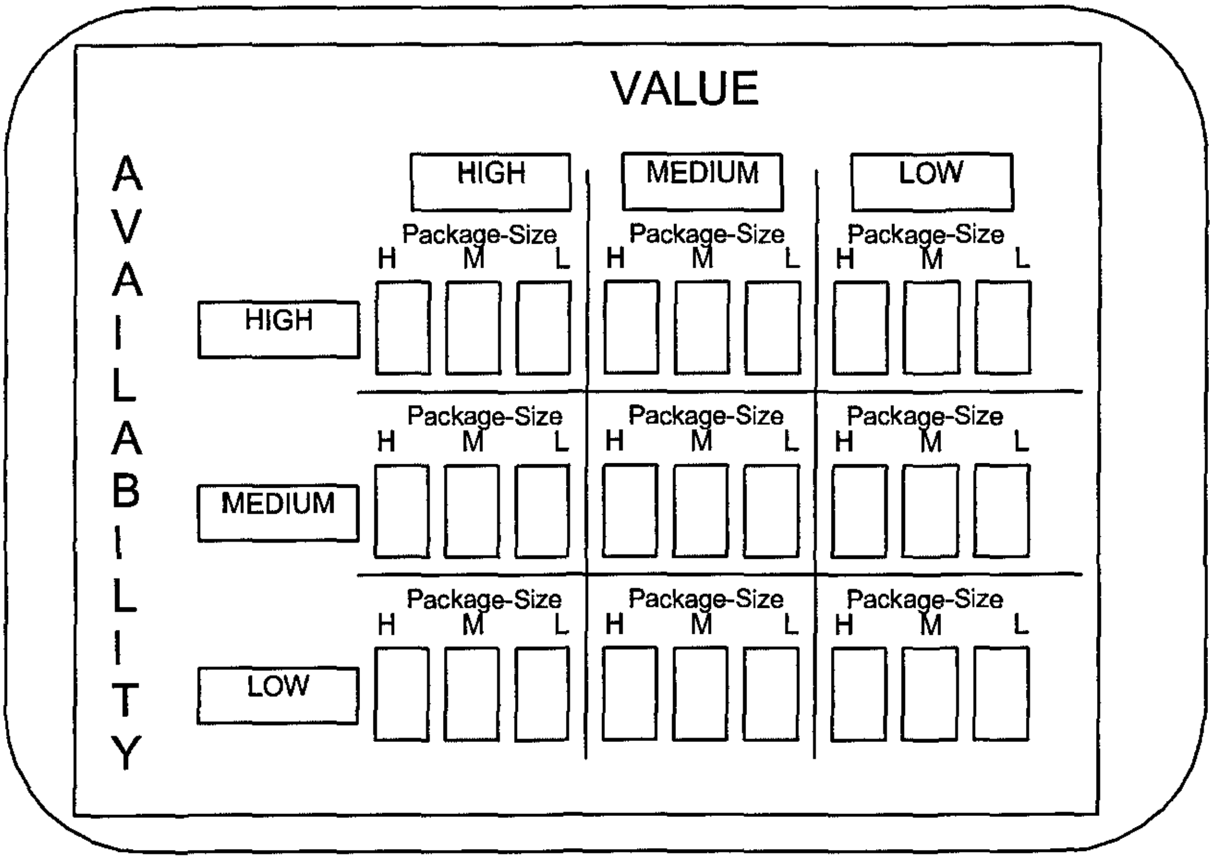


Figure 5-2: Example of Sorting Categories in Experiment 4

Each separate 'pile' was 9.5cm x 11.5cm in size. The overall sorting area in Experiment 4 was 84cm X 120cm.

5.4.4 Procedure

The procedure in Experiment 4 was similar to that of Experiment 3 except that Value, Availability & Package Size needed to be considered together at each individual sort, and not in isolation as previously.

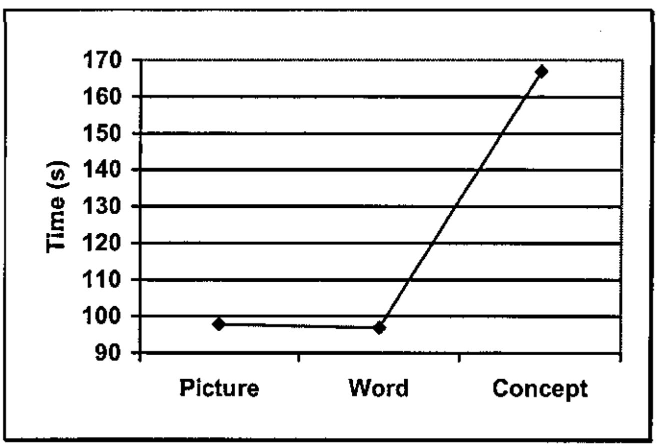
5.5 Results & Conclusions

The results in this section describe what was found in Experiment 4 (i.e. when levels of all three iconic elements [i.e. Ball Size, Metal Type & Height] had to be sorted at the same time). They therefore differ from those in Experiment 3 where only one iconic element needed to be sorted at any one time. The results here refer to time taken to sort the cards (by picture label, word label and concept label respectively), as well as the number of errors made while sorting in these different conditions.

5.5.1 Time

Differences Across Sorting Conditions

The mean decision times across all participants for all 27 cards are shown below:



Graph 5-5: Mean Decision Time per Sorting Condition In Experiment 4

	Count	Mean	Std. Dev	Std. Error
Picture	20	97.8	47.2	10.5
Word	20	96.8	53.7	12.0
Concept	20	166.9	129.3	28.9

Table 5-9: Means Table of Times Across Sorting Conditions In Experiment 4

As in Experiment 3, the exploratory results indicate that the mean decision time in the Concept condition is the longest, followed by the Picture and then the Word condition. A one way repeated measures ANOVA was then used to determine whether the above differences were statistically significant:

Analysis of Variance

Source	df	SSq.	MSq.	F-Value	p-Value
Participant	19	231835.667	12201.887		
TIME	2	64739.100	32369.550	6.730	0.0031
TIME*Participant	38	182776.233	4809.901		

Table 5-10: ANOVA Table of Time Results in Experiment 4

The results indicate that the effect of sorting condition on decision time is highly significant. This means that it took participants longer to assign the representations to a particular category, when this category was defined in terms of a concept (E.g. 'High' Value, 'Medium' Value, Low Value) as opposed to when the category was defined in terms of a description (E.g. High Height, Medium Height, Low Height).

Post Hoc Analysis

A series of mean contrasts was subsequently performed in order to investigate the significances between the sorting conditions when paired.

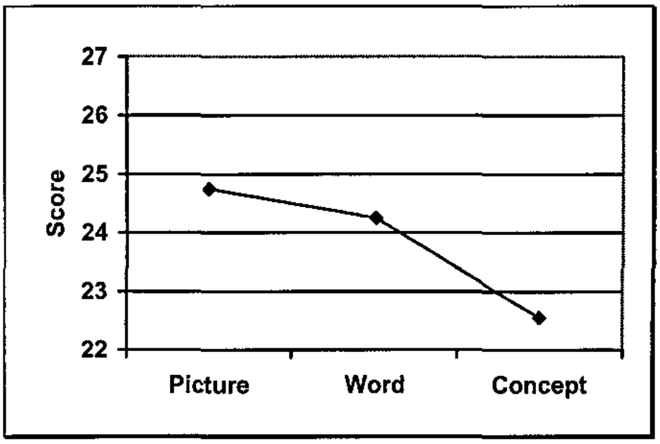
	df	SSq	MSq	F-Value	P-Value
Picture v Concept	1	47817.225	47817.225	9.941	**0.0032**
Word v Concept	1	49280.400	49280.400	10.246	**0.0028**
Picture v Word	1	11.025	11.025	0.002	0.9621

Table 5-11: Post Hoc Means Contrast Analyses Of Sorting Conditions in Experiment 4

The results of the post-hoc tests show that there is a significant difference between picture and word Iconic elements and the concept condition.

5.5.2 Accuracy

The mean number of cards (max=27) sorted correctly in each condition is shown below:



Graph 5-6: Mean Scores (max=27) Per Sorting Condition in Experiment 4

	Count	Mean	Std. Dev	Std. Error
Picture	20	24.750	3.177	0.710
Word	20	24.250	2.918	0.652
Concept	20	22.550	5.482	1.226

Table 5-12: Means Table of Errors Across Sorting Conditions In Experiment 4

As in Experiment 3, the exploratory data results indicate that the mean score is highest in the Picture condition followed by the Word condition and lastly the Concept condition.

Friedman's Rank Test for *k* correlated samples was used in order to determine if the scores produced across sorting conditions were statistically significant.

	Number of Groups	Friedman Statistic	p-Value
Sorting Condition Score	3	1.969	0.3737

Table 5-13: Friedman Test Result For Accuracy Across Sorting Conditions in Experiment 4

As in Experiment 3, the results also indicate that there was no significant difference in accuracy between sorting conditions.:

Conclusion

It can be concluded from the results of Experiment 4 that sorting representations on the basis of an abstract concept takes significantly longer than when this sorting is carried out according to the Iconic element features of the representation. There is no difference between sorting by pictorial description label, and by verbal description label. Accuracy was not shown to be affected by sorting condition .

5.6 Discussion

The combination of the results from Experiment 3 and Experiment 4 has produced some interesting findings. In Experiment 3 when the sorting task was reasonably simple there were no statistically significant results produced, however when the complexity of the task was increased in Experiment 4 some highly significant differences appeared. The chief finding here was that participants took significantly longer to sort representations when they were required to do this according to the 'company share' concept as opposed to when they were supposed to do this according to a Iconic element description (e.g. "large" balls). Interestingly it made no difference whether the Iconic element description took on a verbal or pictorial form.

In Experiment 3 a breakdown of sorting times across different conditions was made (e.g. Ball-size, Colour & Height). It may have been the case that participants found one of the visual Iconic elements (e.g. colour) significantly more difficult to sort than the others – however this did not prove to be the case. This has important implications for subsequent experiments and provides re-assurance that subsequent results are unlikely to be biased due to this factor.

The fact that there were no differences produced in terms of accuracy across the experiment, is one which would be hoped for, as all participants were asked to sort the representations as quickly as possible ensuring that no mistakes were made. A lack of a difference between conditions indicates that this was so, and that no one condition was too difficult for this to be achieved. An emphasis on either speed or accuracy is important given the fat that the pursuit of either can lead to qualitatively different strategies being adopted (Vessey, 1994).

5.6.1 Task Strategy

The use of different strategies, however is an important consideration in determining exactly what the increased time in the concept condition indicated. The question is of relevance as there are a number of strategies which could have been adopted to complete the task depending on how extensively the labels on the sorting board were used.

In the simple experiment (Experiment 2), it became evident that the labels played a relatively minor role in carrying out the task . Participants were therefore quickly able to learn that a representation with a certain appearance should be put in a certain pile. Once this had been done, 'gold' balls could be translated directly in the movement of an arm to a certain pile, regardless of the labels which denoted the pile. This may have been why no difference in time could be seen between conditions in this experiment.

In the complicated experiment (Experiment 3) it was more difficult to use this strategy, firstly because three variables had to be sorted at once, and secondly because each card had an individual position. Movements were not therefore repeated in the way they had been in the previous experiment. A number of strategies could therefore have been followed:

The clearest and most straightforward strategy was that the labels on the sorting board were used to guide the arm to the exact position for every variable on each card. This is most likely the strategy that was followed at the outset, but would assume that the position of iconic cues were never learnt or translated into movements, and is probably unlikely.

A second strategy may have been that certain positions on the sorting board could have been learnt to be relevant for certain iconic elements (i.e. 'gold balls go at the top'). Given that there were 27 piles, and participants were new to the task, it is probable that the position of different iconic elements were learnt in a piecemeal manner, and that the time reflected a combination of direct translations of iconic element to arm movement, and reading of the labels. This being the case, it may be that a distinct shift in strategy would appear as subject learnt and mastered the most efficient and least effortful way of completing the task, which would ultimately lead to no difference between conditions if enough experience was gained.

Nevertheless a difference between conditions was seen, and as the task needed to be learnt it is likely that this did reflect at least some need to read the labels and make translations from appearance to pictorial description, verbal description or concept description. Interestingly, there was no difference in time between the picture label and verbal label condition. It may have been the case that the picture condition would have been quicker as no translation was required into a different modality, i.e. verbal description. This was not the case however. One possible reason is that the picture labels themselves required some degree of decoding. It may therefore have been necessary to work out exactly what aspect of the picture labels was relevant to the current card. In the verbal label condition, the relevant aspect was spelt out explicitly, hence although a degree of translation was required, the labels may actually have been easier to use – explaining the lack of time difference seen here.

It is difficult to ascertain exactly what processes are occurring which lead to the additional time in the concept condition. One highly likely scenario is that the variables on each card were separately recognised and the meaning of each of these needed to be remembered. Presumably it is the remembering process which took the extra time. The experiment would however benefit from being repeated and obtaining a more comprehensive portfolio of results, extending to a short interview to gain a better idea of the strategy that was used, and what participants felt lead to longer times in the concept condition.

5.6.2 Experimental Issues

There are also a few additional issues which should be borne in mind relating to the methodology, measurement and subject samples. Firstly, all the experiments in this study have been derived from the use of a physical card sorting procedure. While this has still allowed meaningful results to be gathered, it would have nevertheless have been more desirable to carry out the experiment via an electronic medium. This would have allowed for more accurate results to be gathered as well as for individual card times to be measured instead of the broad task completion time used here. This might then give some insight strategy change deriving from learning. The reason actual cards were used was largely due to the logistical problem of representing 27 category identifiers on the 15" monitor available, nevertheless electronic measurement would be preferable.

It should also be mentioned that the number of participants used in this experiment was somewhat less than would be optimally desired. In Experiment 3, a total of 18 participants took part, which due to the between-subject design of the experiment, meant that there were only 6 in each Iconic element condition. While the Iconic elements did not form the main subject of investigation, the experiment could usefully be repeated with a larger number of subjects in each condition.

5.6.3 Summary

In summary, this experiment has revealed that the process involved in sorting multidimensional icons based on their meaning, takes longer than sorting the icon based on a verbal or pictorial description of its constituent elements. This additional time can only be witnessed when the translation task is demanding however. One potential reason for this may be that different strategies are adopted due to the complexity of the task at hand.

The next experiment will focus on whether there are beneficial implications of this translation process when compared to other types of representation which do not require such a translation. The next experiment will also focus on how users view the need to use such a translation process, and whether this is found to be beneficial subjectively as well as objectively.

Chapter 6 - EXPERIMENT 4

6.1 Introduction

In the last experiment it was demonstrated that there is a cognitive cost associated with assigning meaning to analogical representations. This experiment will now focus on the utility of this cost, and the subjective perception surrounding the use of analogical representations.

The task which will be used in this investigation is a categorisation task. Analogical representations will also be compared to more traditional representation methods in the same task. A key question guiding the investigation is: Can well chosen multidimensional icons lead to more effective performance, when an idea of the level of individual iconic elements (e.g. value, availability) within the entire representation is necessary?

Implicit in the use of any method of representing data, is the ability to ignore irrelevant variables and concentrate on relevant ones. As the individual variables within an iconic representation are often combined into the same visual object (e.g. ball size and ball colour) it may also be the case that multidimensional icons are less effective in allowing irrelevant variables to be ignored. Both the ability to identify and read relevant variables while ignoring irrelevant variables will therefore be focussed on in this experiment.

An additional important aspect which concerns the overall context of use of multidimensional icons is how users perceive them. The vast majority of users will already have gained a large amount of experience with traditional ways of representing variables such as tables and graphs, and will have been educated in both how to read and construct them. Multidimensional icons therefore represent a challenge in this regard as the conventions necessary to use them will differ from icon to icon. It will also almost inevitably be the case that users will not have encountered individual iconic designs previously. The question of how people perceive such novel representations is therefore an interesting one in this context, as is how this perception differs once some experience has been gained with any given iconic design.

Such questions are important as any biases which can be revealed may have implications for the commercial uptake of applications which make use of Multidimensional Icons. If biases against such novel representations are found to exist, it is likely to be the case that a process of education or promotion is necessary to convince potential users of the benefits of such icons. If these biases are maintained in the face of more effective performance, then the job of promoting the uptake of multidimensional icons can be viewed as even more challenging.

6.1.1 The Task

The issues described will be investigated in the context of a categorisation task. The objects requiring categorisation will be the 27 (3x3x3) different levels of the 'high' analogy visualisation already used in the previous two experiments. As a comparison, these 27 different representations will be represented in graphical and verbal / tabular form and compared directly.

The task will involve categorising each of the representations in terms of the level of value and availability which they feature. This involves identifying the visual elements within the representation which represent value and availability. The task also involves suppressing the 'Package–size' variable, which is not required for the task here. Each representation will therefore fall into one of (3 levels of

'Value' x 3 levels of 'Availability') nine groups and will require allocation to one of these. In order to investigate perceptions of these various representation types, participants will be required to fill out a questionnaire both before and after using the representations to gain an idea of how their judgements of the representations have changed.

To summarise then, the research questions which will be focussed on in this experiment are:

- How well does analogy support the identification of aspects in comparison to traditional graphs and verbal representations?
- How do people perceive the effectiveness of such 'analogical' representations both before and after use?
- Is this perception accurate?

6.2 Method

EXPERIMENT 2

6.2.1 Participants

24 students at Loughborough (14f, 10m) aged 20-35 volunteered to take part in the study and were paid £2.50 for their participation. All participants certified that they possessed no serious visual impairments. Each participant completed all three within-subject conditions in the experiment, but the order in which each type of representation was encountered at all stages of the experiment was counterbalanced in order to avoid order effects. Each participant was therefore randomly assigned a pre-designated experimental 'path' before commencing the experiment.

6.2.2 Task

The experimental task which participants were required to perform was a simple judging task. This involved judging the levels of 'Value' and 'Availability' (High, Medium or Low) in each representation and pressing one of nine buttons (Figure 6-1) next to the representation to indicate which of the nine (3x3) possible combinations the representation showed.

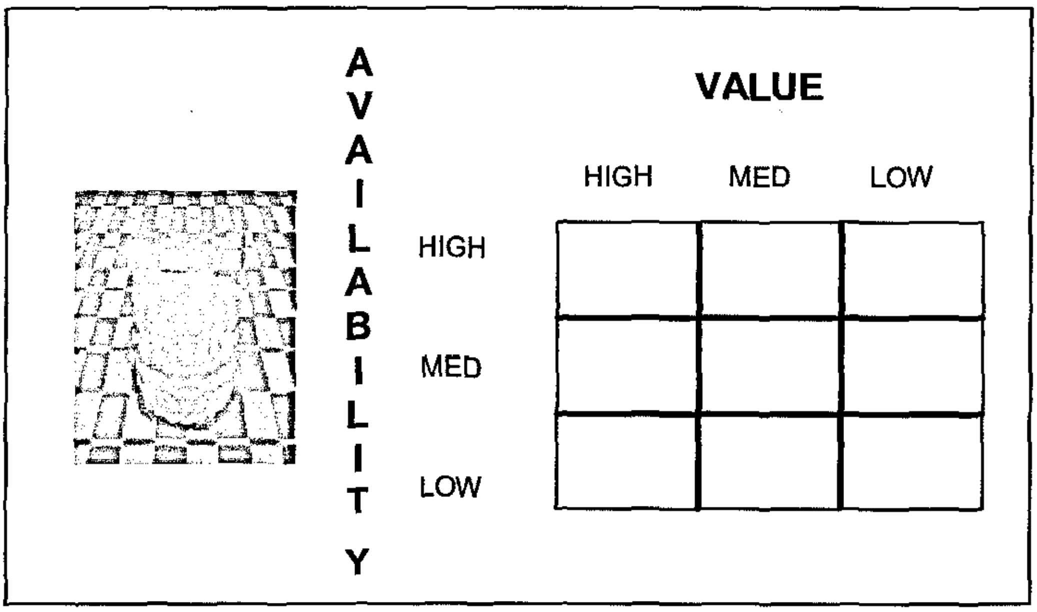


Figure 6-1: Response Button Configuration

Package-Size was included as a variable featured on the representations, but was not required to be judged in the task. This served two purposes. Firstly it aided clarity of the experimental task screen as it would have been difficult to include 27 possible response buttons in addition to a 'question representation' on a 15" screen. Secondly however , the omission of Package-Size as a variable to be judged meant that it served the additional experimental purpose of acting as a 'distraction' variable. Exactly how well participants found they were able to disregard irrelevant information could then be assessed in the questionnaires.

6.2.3 Stimuli & Apparatus

Representations

Three types of visual stimuli were used in the study:

Analogy

The Analogy representation was the 'high analogy' or container representation featured in previous experiments. This was used as this particular representation represented the epitome of analogical representations from those used within this thesis.

Graph

The second type of representation was a bar graph, featuring the three elements 'Value', 'Availability' & 'Package-Size' along the x axis and the three discrete value of 'High', 'Medium' & 'Low', on the y axis. Each bar featured a unique colour to in order to mirror the automatic colour coding of bar graphs which takes place in many statistical and spreadsheet applications. In addition it was felt that as the labels were written clearly in black font at the base of the graph, the coloured bars would help performance on this representation, and would rule out the possibility that the distinctiveness of shape of the variables in the analogy condition were the reason for any performance advantage.

Verbal

The third representation was set out in a verbal format with the concepts set out along the left-most margin and the value for each case specified in verbal form. This representation was laid out in such a form to aid clarity and approximate the layout which may be found in a table

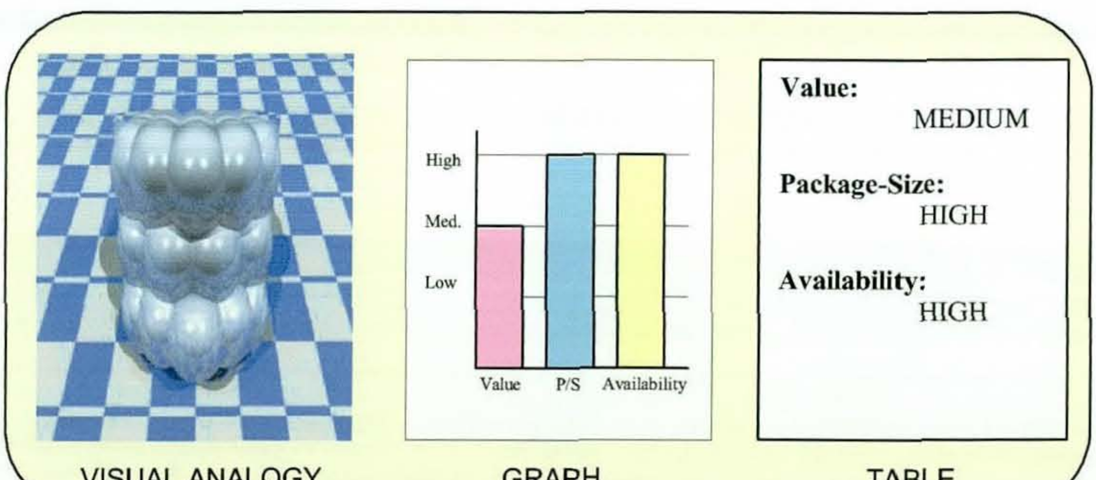


Figure 6-2: Representations Used In Experiment 2

Altogether there were (3x3x3) 27 stimuli for each visual condition.

Questionnaires

Two questionnaires (Appendix 6-1) were used in the experiment – one of which was provided at the start of the session, after an initial cursory explanation of the task (but before the training or experimental tasks had been completed) and one which was provided at the end of the session after the task had been completed.

The questionnaires were identical to each other with the small exception of grammatical tense changes (future for the initial questionnaire, past for the end questionnaire). The aim of the questionnaires was to collect opinions at a particular time point concerning five different aspects of the representations, these being: opinions as to the speed and accuracy facilitated by a particular representation, the visual appeal of each representation, the confusion potential of each representation and finally a general measure of preference. The four initial aspects were probed twice in each questionnaire, while a preference ranking was elicited once at the end of the questionnaire. Each questionnaire featured space for open-ended comments, while the initial questionnaire also collected demographic data relating to the participant.

The questionnaires used simple rating scales (one for each representation) which were grouped together in each question (Figure 6-3). This design therefore allowed both for a rating value and for a clear hierarchy to be established between representations. The order in which each representation featured was rotated across questionnaires to eliminate any order effects.

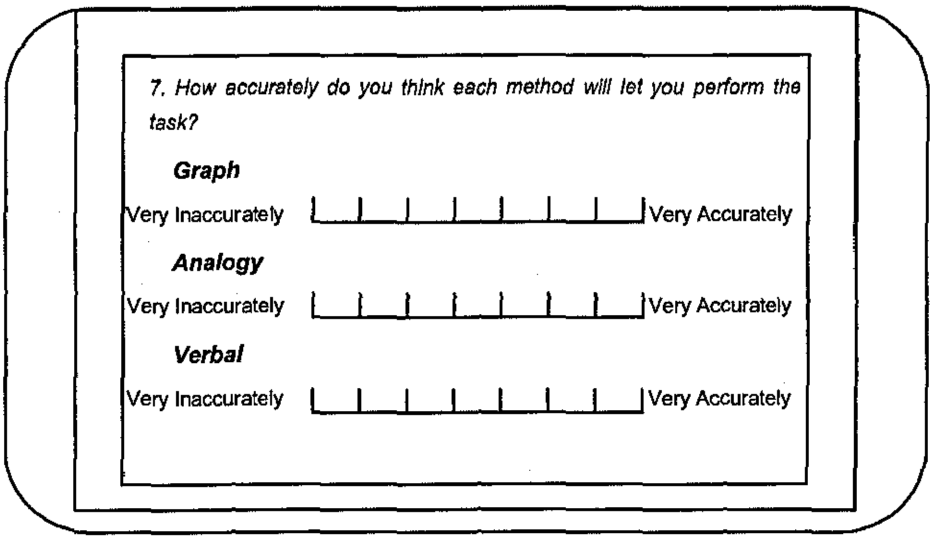


Figure 6-3:Example of Question Design In Experiment 2

Presentation Method

The experiment was administered using the HyperCard™ program on an Apple imac platform (incorporating a 15" monitor). HyperCard™ allows stimuli to be incorporated onto a series of electronic 'cards' onto which can be placed a variety of programmable buttons and fields (Appendix 6-2, 6-3). The buttons can then be activated using a computer mouse and the time and results of each mouse click automatically monitored. All measurements were therefore taken via HyperCard™. Each representation (Analogy / Graph / Verbal) required two programs – a training program (Appendix 6-4) and an experimental program. (Appendix 6-5)

6.2.4 Procedure

The experiment consisted of four principal stages:

- Initial Questionnaire
- Instruction & Training Session
- Experimental Task
- Final Questionnaire

All participants first signed a consent form (Appendix 5-4) indicating that they possessed no visual impairment which might compromise the results of the experiment. After this a short explanation of the task was given in order that participants would be able to make a naïve judgement on how well the representation would be likely to help them perform the task. To this end, examples of all three representation types were displayed while the overall purpose of the sorting task was explained with reference to how the representations would be used for the task. Once participants indicated that it was clear to them what they would be required to do they were then given the first questionnaire to complete.

On completing this, each participant was assigned to one of three representation instruction and training sessions. Each of these featured a computerised practice trial session which required participants to carry out the actual task with one of the three representations (i.e. analogy, graph or verbal). An example representation was therefore shown and the job of the participant was to judge which of nine combinations of value and availability the representation featured and press the corresponding button (Figure 6-1). Participants were able to 'graduate' from the practice session once they were able demonstrate competency at the task – i.e. to judge correctly 10 representations in a row.

Once the practice session had been successfully completed, the experimental task for the same representation began immediately. Each of the (3x3x3) 27 combinations of Value, Availability and Package-Size for each representation was shown on the screen in a random order, and required to be classified according to the level of Value and Availability that was shown. After the experimental task for the first representation had finished, participants then repeated the instruction and training sessions for the other two representations.

Once these had been finished, each participant was given the final questionnaire. The brought the experiment to an end after which participants were de-briefed on the purpose of the experiment, and shown their relative performances if desired.

6.3 Results

There were two classes of measurement taken during the experiment: Objective and Subjective. Measurements taken during the experimental task formed the objective results and consisted of time of each mouse click, along with identity of the button clicked. This raw data produced in the HyperCard program was refined using Microsoft Excel to produce the time spent per question, together with the accuracy of each question. This data was then statistically analysed using the statistics software package – Prism™.

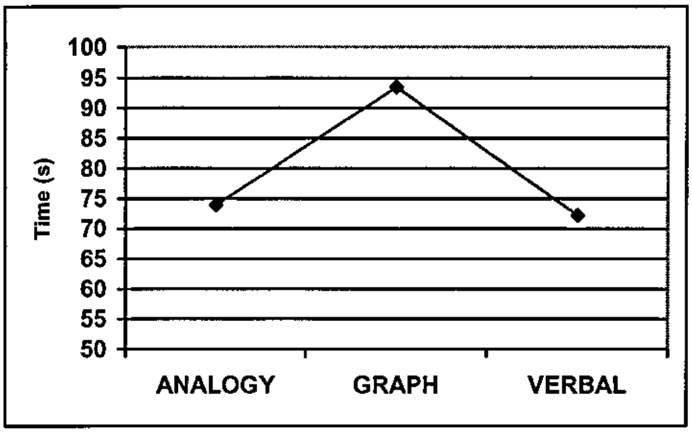
Subjective data was formed by the answers given in the questionnaires. These took the form of scores out of 7 regarding perceived speed and accuracy, perceived distraction of irrelevant variables, and visual appeal. Each construct was probed twice and the mean score extracted to give a measure of intensity with 7 as maximum and 1 as minimum. A ranking of representation 'preference of use' was also obtained – in this instance, participants were forced to rank the representations as 1st, 2nd & 3rd.

The two classes of data will now be considered in turn starting with the objective data, moving onto the subjective data, before considering the combination of the two

6.3.1 Objective Data

Speed

The data included here is comprised of the times collected from the correct answers. The times for incorrect answers were disregarded, and the mean of the correct times for that particular subject substituted. An initial plot of the response times across conditions shows that the graph clearly lead to the longest response times, with the analogy representation having a slightly longer response time than the Verbal Condition:



Graph 6-1: Mean of Representation Response Times In Experiment 2

	Mean	SD
ANALOGY	73.9	23.5
GRAPH	93.5	19.0
VERBAL	72.2	17.2

Table 6-1: Means and Standard Deviations of Response Times in Experiment 2

A one-way Analysis of Variance (ANOVA) was then performed on the data from all 24 subjects to investigate the significance of the differences.

ANOVA Table	SS	df	MS	F	p
Treatment (between columns)	6699	2	3349	17.98	0.0001
Individual (between rows)	19240	23	836.5		
Residual (random)	8568	46	186.3		
Total	34510	71			

Table 6-2: ANOVA Summary Table of Time Across Representations In Experiment 2

A main effect of representation type on speed is evident at a high level of significance. In order to examine exactly which pairings contributed to the difference, the post-hoc Tukey's Multiple Comparison Test was performed on each pairing.

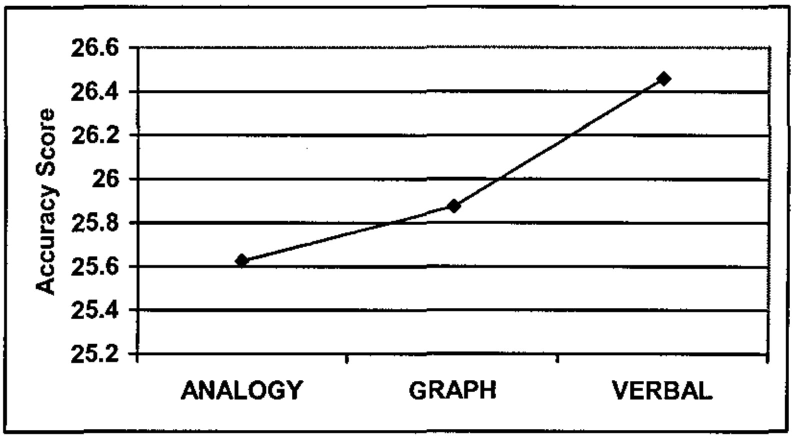
Tukey's Multiple Comparison Test	Mean Diff.	q	P value	95% CI of diff
ANALOGY vs GRAPH	-19.56	7.021	**P < 0.001**	-29.11 to -10.01
ANALOGY vs VERBAL	1.696	0.6089	P > 0.05	-7.857 to 11.25
GRAPH vs VERBAL	21.26	7.63	**P < 0.001**	11.70 to 30.81

Table 6-3: Tukey's Multiple Comparison Test of Speed Pairings In Experiment 2

The results from the Post-Hoc tests reveal that the significant differences lie in the comparison between the graph condition and the other two conditions. There is no significant difference between the Analogy & Verbal condition in terms of time taken. It is possible to conclude therefore that the graph condition gives rise to a significantly slower performance than the other two conditions.

Accuracy

A plot of accuracy scores (out of 27) reveal that the Verbal condition leads to the greatest accuracy followed by the graph condition and then the Analogy condition



Graph 6-2: Plot of Score (max.27) across representation conditions In Experiment 2

	Mean	SD
ANALOGY	25.6	1.7
GRAPH	25.9	1.2
VERBAL	26.5	1.5

Table 6-4: Mean & Standard Deviation of Scores in Experiment 2

A test was then used to explore if there was a significant main effect of representation type on accuracy. The nature of the data dealing as it did with discrete 'scores' meant that a non-parametric Friedman test was used. This revealed a Friedman statistic of 9.652, with a corresponding p-value of 0.008. This is a significant value.

In order to uncover which pairs lead to this significant difference, the post-hoc Dunn's Multiple Comparison Test suitable for non-parametric data of this type was used. This lead to a rather intriguing result:

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	1.5	P > 0.05
ANALOGY vs VERBAL	-15	P > 0.05
GRAPH vs VERBAL	-16.5	P > 0.05

Table 6-5:Summary of Dunn's Multiple Comparison Test of Accuracy Across Conditions In Experiment 2

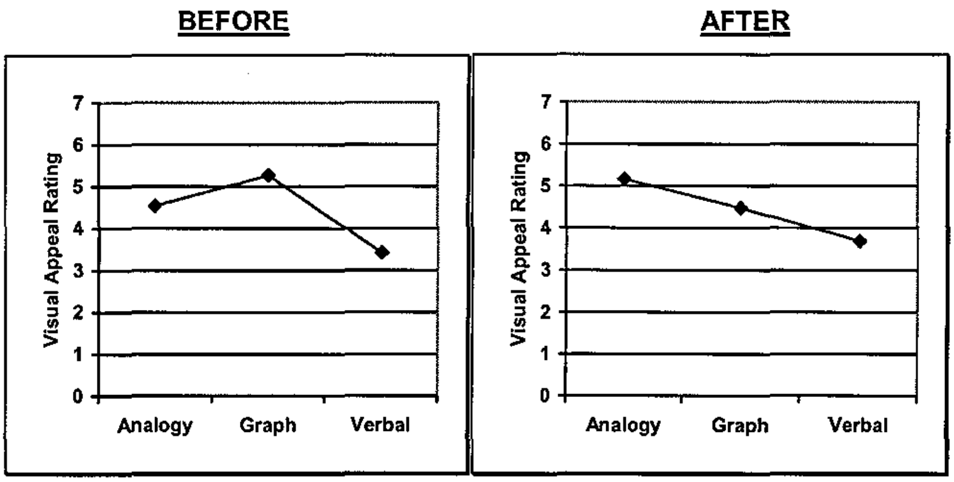
No single condition when compared with another in a pair comparison yields a significant difference, despite the fact that there is an overall effect of representation on accuracy.

6.3.2 Subjective Data

Intra-Construct Analysis

The Subjective data collected from the questionnaire was designed to probe five different aspects of the representations – these being visual appeal, speed of use, accuracy, ability to focus on relevant information and overall preference. Data pertaining to the first four of these was collected using rankings given to two different questions. Visual preference was obtained through use of a rating scale. The ratings for each construct were first checked to ensure that the profile from the question pair was similar. Where necessary (e.g. where questions had probed for opposite ends of the construct continuum) inversions were performed on the data so that the ratings were oriented in the same direction. The collective mean from the two questions was then used to give an overall construct rating. Graphs of ratings 'Before' and 'After' the task are shown below together with results from Friedman's Rank Test for *k* correlated samples and Dunn post-hoc tests to investigate if the differences between means are significant.

Visual Appeal



Graph 6-3 : Mean Rating of Visual Appeal Before & After Task (7=Good / 1=Bad)

It can be seen here that the graph is rated as having the highest visual appeal before the task, with the analogy representation being rated as second most appealing. After the task the analogy representation is seen as the most appealing. This is possibly an effect of the actual effectiveness of the analogy representation.

Friedman tests reveal an overall effect of representation type on visual appeal rating both before (F[df,2]=20.59, p=<0.001) and after (F[df,2]=12.82, p=0.0016) the task. Post Hoc Test results are shown in the tables below:

BEFORE TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	-17.5	**P < 0.05***
ANALOGY vs VERBAL	13	P > 0.05
GRAPH vs VERBAL	30.5	**P < 0.01****

Table 6-6: Post Hoc Analysis of Visual Appeal Ratings before Task in Experiment 2

AFTER TASK

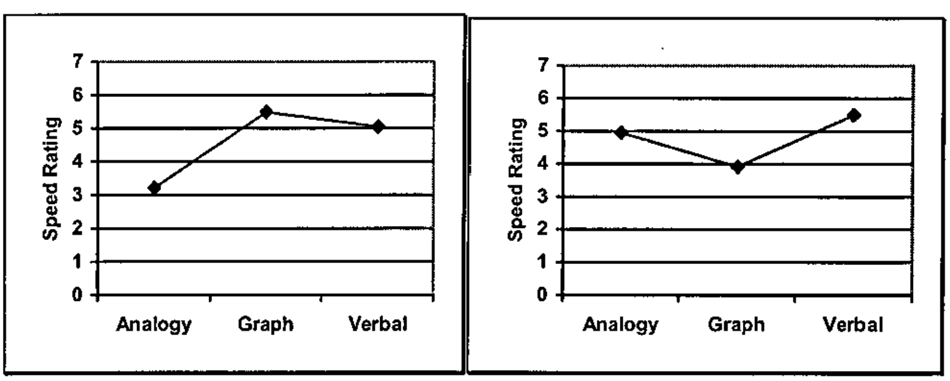
Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	13	P > 0.05
ANALOGY vs VERBAL	23	**P < 0.01****
GRAPH vs VERBAL	10	P > 0.05

Table 6-7: Post Hoc Analysis of Visual Appeal Ratings after Task in Experiment 2

These reveal very different patterns of differences with the Analogy vs. Verbal pair comparison being the only comparison giving rise to an insignificant difference before the task and the only comparison giving rise to a significant difference after the task. On looking at the plot this appears primarily to be due to the rise in appeal rating of the analogy once the task had been completed, as well as the fall in the appeal of the graph.

Speed Of Use

BEFORE AFTER



Graph 6-4: Mean Rating of Speed of Use Before & After Task (7=Fast / 1=Slow)

In terms of speed of use, the graph is anticipated as leading to the quickest times, slightly ahead of the verbal method. The analogy is perceived as being the least effective. After the task, the profile actually matches that of the objective data (although it is inverted in this graph as higher=quicker in this case). Hence the objective opinion of the graph slips from best to worst.

Friedman tests here show an overall effect of representation type on speed rating both before (F[df,2]=25.1, p=<0.001) and after (F[df,2]=12.82, p=8.069) the task. Post Hoc Test results are shown in the tables below:

BEFORE TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	-32.5	**P < 0.01****
ANALOGY vs VERBAL	-23	**P < 0.01****
GRAPH vs VERBAL	9.5	P > 0.05

Table 6-8: Post Hoc Analysis of Speed Ratings before Task in Experiment 2

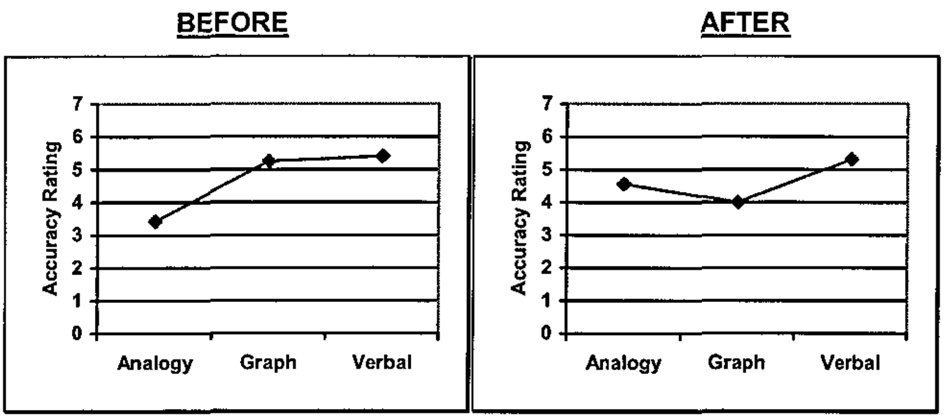
AFTER TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	13.5	P > 0.05
ANALOGY vs VERBAL	-4.5	P > 0.05
GRAPH vs VERBAL	-18	**P < 0.05***

Table 6-9: Post Hoc Analysis of Visual Appeal Ratings after Task in Experiment 2

Again, these show a very different pattern of differences. The graph vs. verbal comparison gives rise to the only significant difference in mean ratings before the task, and the only significant difference after it. While the subjective speed profile post-task is similar to the actual objective speed profile, it could be proposed that participants are not fully able to appreciate that the analogy representation is significantly quicker than the graph

Accuracy



Graph 6-5 Mean Rating of Accuracy Before & After Task (Max=7)

The plot of subjective opinions of accuracy reveals that the pre-task opinion of the verbal method as being the most effective is correct, while once again the analogy is perceived as least effective. After the task, the graph is perceived as least effective, when in actual fact according to the means plot of actual accuracy, the analogy condition lead to less effective performance (although this was not at a statistically significant level). The general decline in popularity of the graph therefore seems to extend to situations where it is unwarranted.

Friedman tests reveal an overall effect of representation type on accuracy rating both before ($F[df,2]=22.33$, $p=<0.001$) and after ($F[df,2]=7.471$, $p=0.024$) the task. Post Hoc Test results are shown in the tables below:

BEFORE TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	-26.5	**P < 0.01****
ANALOGY vs VERBAL	-24.5	**P < 0.01****
GRAPH vs VERBAL	2	P > 0.05

Table 6-10: Post Hoc Analysis of Accuracy Ratings before Task in Experiment 2

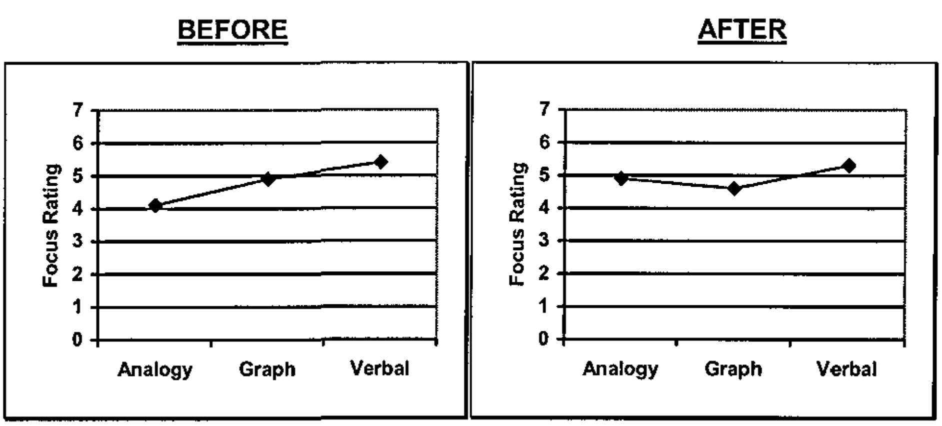
AFTER TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	5	P > 0.05
ANALOGY vs VERBAL	-12.5	P > 0.05
GRAPH vs VERBAL	-17.5	**P < 0.05***

Table 6-11: Post Hoc Analysis of Accuracy Ratings after Task in Experiment 2

The same inverted pattern is present here in terms of pair comparison significances as with the previous constructs analysed. The pair comparison here which bucks the trend is that of graph and verbal comparisons. Again this appears to happen because the analogy rises in rating, while the graph falls significantly in rating.

Suppressing Irrelevant Information



Graph 6-6: Mean Rating of Ease of Focus On Relevant Information Before & After Task (Max=7)

The plot reveals here that the analogy representation is perceived as being the least likely to allow irrelevant information to be ignored, with the graph being the next most effective, and the verbal method the most effective. After the task, as has often been shown to be the case, the graph method has fallen in rating, while the analogy has improved. The verbal rating appears to remain the same.

Friedman tests revealed that the differences between means before the task were significant (F[df,2]=8.562, p=0.014), and insignificant (F[df,2]=5.106, p=0.078) after the task.

BEFORE TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	-9	P > 0.05
ANALOGY vs VERBAL	-19.5	**P < 0.05***
GRAPH vs VERBAL	-10.5	P > 0.05

Table 6-12: Post Hoc Analysis of Focus Ratings before Task in Experiment 2

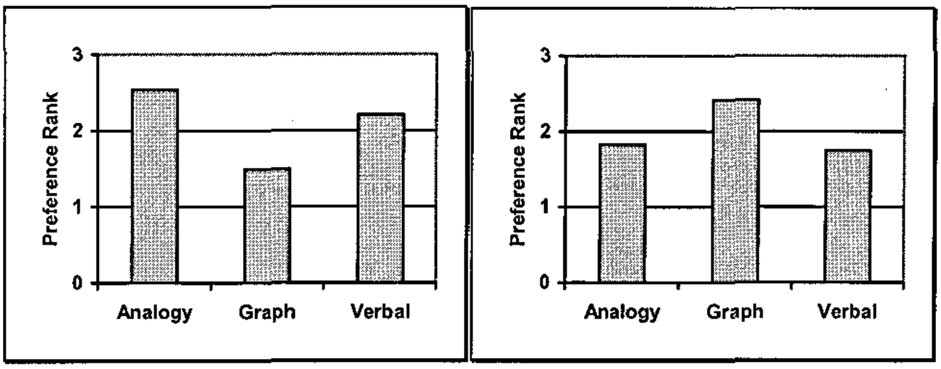
AFTER TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	9.5	P > 0.05
ANALOGY vs VERBAL	-5	P > 0.05
GRAPH vs VERBAL	-14.5	P > 0.05

Table 6-13: Post Hoc Analysis of Focus Ratings before Task in Experiment 2

A Post-hoc test of the pre-test differences reveals that the Analogy Condition is significantly perceived as being worse than the verbal method. This significance in difference disappears after the test. All other comparisons are insignificant.

Overall Preference



Graph 6-7: Mean Ranking of Preference Before & After Task (Best=(1st) / Worst =3(rd))

The mean preference ranking mirrors many of the subjective ratings with the graph being ranked as most preferred pre-task and least preferred post-task. The analogy representation is least preferred pre-task and is only narrowly beaten by the verbal representation post-task. This pattern of preference actually mirrors the objective data as the verbal representation (at least in terms of raw means) was the most effective both in terms of speed and accuracy.

Friedman tests performed on these ranked preferences revealed a significant difference in mean rankings both before (F[df,2]=17.33, p=0.0002) and after (F[df,2]=6.333, p=0.0421) the task.

BEFORE TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	28	**P < 0.01****
ANALOGY vs VERBAL	8	P > 0.05
GRAPH vs VERBAL	-20	**P < 0.05***

Table 6-14: Post Hoc Analysis of Preference Ranking before Task in Experiment 2

AFTER TASK

Dunn's Multiple Comparison Test	Difference in rank sum	P value
ANALOGY vs GRAPH	-14	P > 0.05
ANALOGY vs VERBAL	2	P > 0.05
GRAPH vs VERBAL	16	P > 0.05

Table 6-15: Post Hoc Analysis of Preference Ranking after Task in Experiment 2

Post Hoc tests revealed significant pair differences before the task but none after the task. The pair differences before the task both arise from the graph condition which subsequently falls by a large margin in preference rating after the task, while the graph and verbal condition both improve in rating. The overall effect of actually doing the task is therefore to even out the overall preference rating.

Intra-Representation Analysis

While the last battery of tests showed the various relationships over time between the representations according to the constructs (e.g. Speed, accuracy) measured. They do not give a picture as to whether the ratings within each representation type have changed significantly over time. A series of Wilcoxon's matched pairs signed-ranks tests were performed to investigate this. The results are summarised in the tables below together with an indication of whether the difference measured increased positively or negatively after the task:

ANALOGY

	Sum +,- ranks	W value	P Value	Direction
Visual Appeal	43.5, -166.5	-123.0	**0.021**	▲
Speed	38.0, -238.0	-200.0	**0.0024**	▲
Accuracy	36.5, -173.5	-137.0	**0.0107**	▲
Focus	23.5, -147.5	-124.0	**0.007**	▲
Overall rank	166.0, -24.0	142	**0.0025**	▲

Table 6-16: Summary of Wilcoxon Tests for Analogy Rating Differences before and after Task in Experiment 2

GRAPH

	Sum +,- ranks	W value	P Value	Direction
Visual Appeal	183.5, -47.5	136	**0.018**	▼
Speed	198.5, -11.5	187	**0.0005**	▼
Accuracy	225.0, -6.0	219	**0.0001**	▼
Focus	148.0, -62.0	86	0.096	-
Overall rank	29.0, -224.0	-195	**0.0012**	▼

Table 6-17: Summary of Wilcoxon Tests for Graph Rating Differences before and after Task in Experiment 2

VERBAL

	Sum +,- ranks	W value	P Value	Direction
Visual Appeal	85.0, -125.0	-40	0.46	-
Speed	99.5, -176.5	-77	0.24	-
Accuracy	109.0, -101.0	8	0.89	-
Focus	109.0, -81.0	28	0.57	-
Overall rank	87.0, -18.0	69	**0.030**	▲

Table 6-18: Summary of Wilcoxon Tests for Verbal Rating Differences before and after Task in Experiment 2

The results give a rather consistent picture of the change in attitudes towards the representations. In the analogy case, every rating is significantly higher after the task, while with the graph every rating has significantly fallen apart from one which registered no change. All the verbal ratings remained the same apart from overall ranking which significantly improved.

6.3.3 Summary

To summarise the results, it can be said that the verbal and analogy representation methods both lead to the most effective performance in this sorting task, with the graphical method performing significantly worse in terms of speed. There was no significant difference in terms of errors made.

Opinions of the representations vary markedly before and after the task. Before the task, the 'traditional methods' of the graph and verbal representations are both anticipated as being significantly better than the analogy representation in all measures of performance. The graph is also perceived as having the most visual appeal and is ranked as the method most participants would like to use.

After the task the situation is almost completely reversed. The graph actually results in the least effective performance, and participants are well able to notice this. Consequently every rating of the graph (except ability to focus) shifts significantly downwards. The situation with the analogy is the exact opposite, with every measure shifting significantly upwards, so that it is perceived as equal most effective in every regard. It appears that participants were good at predicting the effectiveness of the verbal method. The ratings barely change therefore. It is recognised as being an effective method both before and after the task.

6.4 Discussion

A number of aims were stated at the start of this particular study. These were:

- How well does analogy support the identification of aspects in comparison to traditional graphs and table type representations?
- How do people perceive the effectiveness of such 'analogical' representations both before and after use?
- Is this perception accurate?

It has been shown that analogical representations can be used with benefit. In this experiment, they proved equally as effective as the representation traditionally considered to be best for data of this type, and better than other commonly used graphical representations where the values necessary to complete the task were explicitly stated.

So why is the analogy representation as good as the verbal representation, while both were better than the graph representation? One explanation is that analogical representation was able to work as well as the verbal representation for two reasons: Firstly, the analogy present in the representation was able to act as a prompt to allow users to remember what the various elements meant (e.g.

height = availability). Secondly, these elements allowed the both the combination of identity and value to be accessed in one position. For example, all the information necessary to understand that a representation showed high value was present in one position (i.e. Within a golden ball).

Taking both these factors into account, this puts the analogical representation on a par with the verbal representation where the labels spelled out the identity of the iconic element (e.g. value) and its level (e.g. high) in close proximity. With the graphical representation on the other hand, the distance between the label identifying the variable (present underneath the x axis) and the height of the bar showing its level (present in different positions according to the height of the bar, but often at a further distance) necessitated a process of visible comparison between the label and the height that it was showing. This may have resulted in longer viewing times.

Were this to be the case, it would present an additional argument in favour of the wider adoption of multidimensional icons in tasks where such comparisons are necessary. As the ability to locate identity of a variable and its level at the same location are not something that bar graphs are easily able to do. This is a documented advantage of diagrams (Larkin & Simon, 1987) applied to the domain of graphs.

In terms of how users initially respond to such novel representations, the broad answer is - not well, although they are found to be attractive in appearance. Curiously this appeal may contribute to the fact that although performance is anticipated as being worse, it is ranked equally with the verbal representation in terms of preference. In contrast, graphs appear to be very positively received initially.

Users perception of the analogy representation as being ineffective is not accurate however, as the objective results show. To compensate for this, users seem to adjust their opinions accordingly after the task, as perceptions of the representations are subsequently much more in keeping with their actual performance. The graph was heavily over estimated before the task, and this over-estimation can be seen to be corrected through the fact that all but one of the ratings for the graph fall significantly, including visual attractiveness rating.

The 'verbal' method appears to have been reasonably accurately rated both before and after the task.

The results demonstrated here have important implications for designers and promoters of information visualisation applications, in as much as any benefit that can be provided by such applications appears not to be intuitively obvious. While "we are drowning in information and need new ways to make sense of it" (Ressler, 1998), methods which make use of explicit visual analogies, are not necessarily perceived as the best way of overcoming this. An additional reason why information visualisation has not developed as has been predicted in some cases may well therefore be because the demand end of the supply-demand chain needs to be created.

Having demonstrated the potential utility of analogical representations in comparison with more traditional representations. The next chapter will focus more on the question of analogy itself. In particular, it will seek to investigate systematic effects of differing levels of analogy.

Chapter 7 - EXPERIMENT 5

7.1 Introduction

The results of previous experiments have so far allowed a scale of analogy to be established and have yielded some idea of what is involved in the process of mapping visual appearance to concept meaning. It has also been shown that a 'high' analogy representation is as good as or better than other traditional representations. Despite the fact therefore that a translation cost is incurred in working out what a multidimensional icons means, it seems that if this is carefully chosen with regard to visual analogy, then it is a potentially beneficial means of portraying related quantitative variables.

This experiment described in this chapter will now seek to investigate the concept of visual analogy in more detail. This will be done in a number of ways: Firstly the multidimensional icons themselves will be compared to see if the different levels of analogy that they contain have any implications for task effectiveness. Secondly the effect of direction of mapping) and how this interacts with visual analogy will be examined. Thirdly the implication of level of visual analogy and the implications this has for strategy will also be examined. The aspects under investigation will now be described in more detail.

7.1.1 Visual Analogy & Task Effectiveness

The concept of task effectiveness has already been looked at in Experiment 3 where the 'high' analogy representation was compared against graphical and verbal means of portraying the same data in a categorisation task. This required the identity and level of two of the three variables in the representations to be extracted and an appropriate response button to be pressed. In that experiment it could be seen that the 'high' analogy representation used was more effective than the graphical method, and as good as the verbal method, in terms of task time and accuracy. This being so despite the fact that the answers had to be extracted from the pictorial representation, while in both the graph and the verbal descriptions they were spelled out explicitly. In this experiment the aspect of extracting relevant variables from the pictorial descriptions will be examined in more detail. Specifically, can relevant identity and level of variable be extracted more quickly from 'high' analogy representations than representations with a lower analogy level. In addition can this extraction process be learnt more quickly and performed with less mistakes?

The task to be used in this experiment will bear some similarities with that just described, but will be more complex. The concept and representations used in previous experiments will be maintained, but the task will be made more complex in that participants will be required to identify whether an 'ideal' company exists or not from a choice of three candidate representations. Identifying the company will involve searching for a particular combination of variables which may involve either one, two or all of the variables in the representations. For one individual question therefore, participants may be told that the company they are looking for has a "Low Availability" &"Medium Value". This requires the identification of the availability, and value iconic elements as well as what the levels of these variables are. All three of the candidate representations then need to be examined to see if they possess this profile. If one does, then it can be chosen, and if none do, then a 'none' decision needs to be made.

The representations to be used to examine these questions will be the 'high' (container) and 'medium' (glass wall) analogy representations. (To emphasise comparison in this experiment however, the 'medium' analogy will be referred to throughout the chapter as 'low' analogy). These representations will be used as from a purely visual point of view as there is little to separate these visualisations. It can be argued however that there is a larger difference in meaning between the two, with the glass container equating better to the concept of a company with a limited amount of share units of which any proportion can be present. Some of these cues are present for the glass wall representation, however the concept of full (all shares available) and empty (no shares available) is not present to such an explicit degree. (See Chapter 4 for a fuller discussion) The presence of a greater number of cues can be hypothesised to help identification of the various elements which in turn might lead to the identification task to be performed here, being carried out more quickly and with less mistakes. In addition the use of explicit real world objects, with which some experience will already have been gained (i.e. the knowledge that a glass can be filled with contents up to a maximum level), can be hypothesised as being easier to learn.

7.1.2 Visual Analogy & Directionality

This experiment will also examine the concept of directionality (or mapping direction) and the importance this plays in multidimensional icons. Within the representations used here it may be that the increased degree of real-world knowledge and structure implicit in the 'container' representation will be more adversely affected by change in directionality than the less structured 'wall' condition. It has not up to now been demonstrated how users react when the mappings within representations using explicit analogies are reversed, and how any effect compares with representations in which the analogy is not so explicit. Such a question also has practical implications for visualisation design. That is to say, should higher level analogies ever take design precedence over the directional mappings of which they are comprised?

7.1.3 Visual Analogy & Strategy

A further issue of interest is whether the representations cause different strategies to be followed to achieve the tasks. Certain aspects of the different levels of visual analogy present in the different representations here, may lead to a clearly identifiable difference in usage. To examine if this is the case, a number of different strategies will be permitted to complete the task. This can be performed by reading which attributes the company to be sought has, either with or without the candidate companies present. This it is hypothesised, may have interference or facilitation effects depending on the strategy adopted to arrive at the answer, and whether this strategy makes extensive use of the external representations to help arrive at the answer or whether a greater use of internal representations is made. While it is not easy before-hand to say which strategy a greater level of analogy might lead to, it is of interest to discover if a different strategy is indeed adopted.

7.1.4 Summary

In summary, this experiment has three goals which are:

- To investigate if visual analogy level leads to a difference for task effectiveness in terms of speed, accuracy and learning rate
- To examine if directionality interacts with level of analogy with regard to task effectiveness
- To examine if analogy level leads to a difference in task strategy adopted

These goals it is hoped, will also allow some practical guidelines to be developed with regard to multidimensional icon design.

7.2 Method

EXPERIMENT 5

7.2.1 Participants

40 students (18m, 22f) from Loughborough University took part in this study, all of whom, had no experience with share dealing, and possessed normal colour vision (Appendix 5-4). Ages ranged from 18-34. Each was paid £2.50 for their participation in the study. There were 4 between-subject conditions in the experiment with 10 participants taking part in each condition.

7.2.2 Task

Participants in the experiment were required to take on the role of 'share-scout' in a fictional stock market. This role involved responsibility for searching out and selecting certain companies deemed desirable according to the prevailing stock market conditions at that time. Figure 7-1 gives an example of a task screen and a set of potential companies from which to choose (Option 2 would be correct in the 'normal' condition)

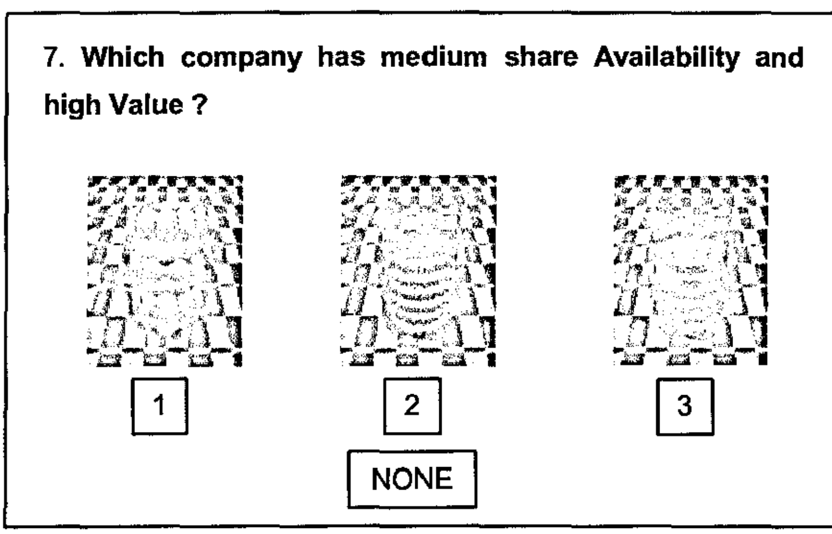


Figure 7-1: Example of Task Screen in Experiment 5

In practice this involved answering a total of 96 multiple choice questions of varying complexity, in which the question provided the information as to the 'ideal' company (Appendix 8-1), and a choice of three representations (of different design according to the condition) provided the potential answers. Participants were required to make a decision as to which of the representations (if any) portrayed the correct combination of variable values, and select it.

7.2.3 Stimuli & Apparatus

Presentation Method

The entire experiment was administered using HyperCard™. This included instructions (Appendix 8-2,3,4,5), training sessions (Appendix 8-6), experimental tasks (Appendix 8-7,8,9) and all measurements (Appendix 8-10). There were a total of four between-subject conditions in the experiment, and each of these consisted of a set of instructions, training program, and four experimental programs (one for each quarter of the experimental session). All of these allowed each participant to proceed at their own pace, and recorded simultaneously the choices and time of all activity on the part of the participant.

Questions

A total of 96 questions featured in the experiment (Appendix 8-1). These were split into three groups – with 32 of the questions asking about 1 variable (E.g. Which company has a low Value), 32 questions asking about the combination of 2 variables (E.g. Which company has a low Value and medium Availability?) and 32 questions asking about the combination of 3 variables (E.g. Which company has a low Value, medium Availability & high Package-Size?). These questions were then randomly grouped into four sets of 24 questions which formed the first, second, third and fourth quarters of the experiment.

Representations

The representations used in this experiment were the Wall (Medium Analogy) & Container (High Analogy) representations. These were used both in the conventional mapping direction (e.g. LARGE = 'HIGH') and also in the reversed direction (e.g. LARGE = 'LOW'). These are illustrated in Figure 7-2.

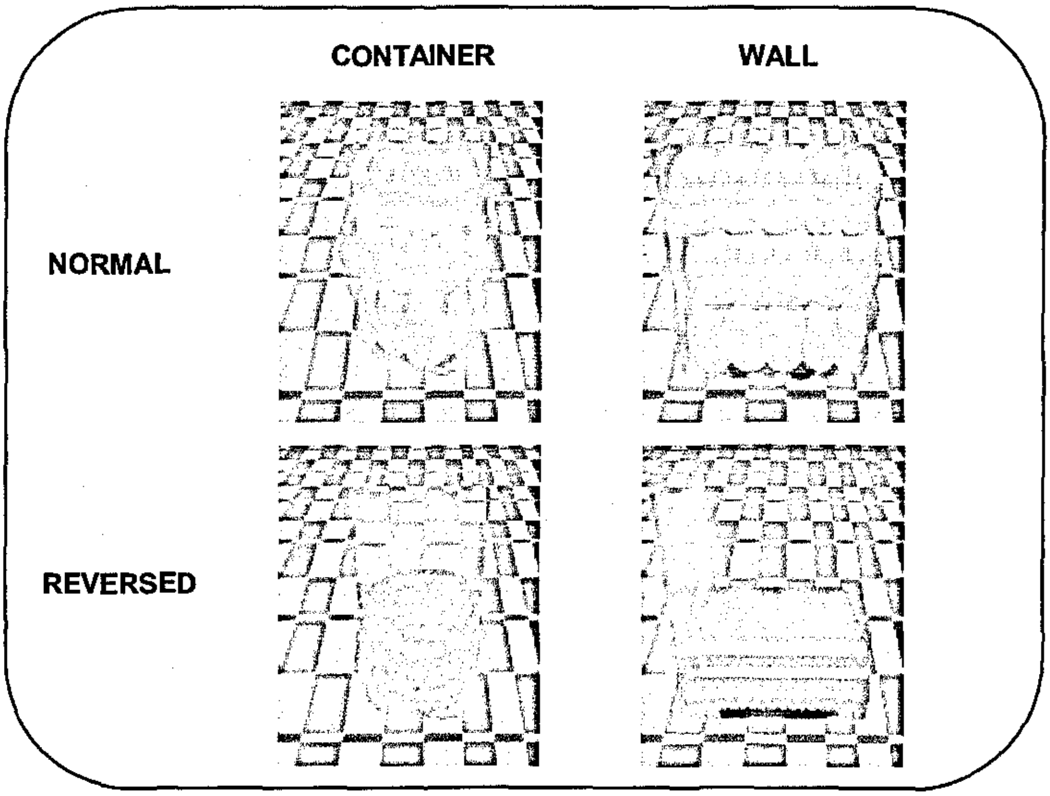


Figure 7-2: Representation Types Used in Experiment 5

Key Card

A 'key' card was provided for participants to use throughout the experiment. This contained all the mappings necessary to answer the questions meaning that there were four in total (one for each condition). These took the form of laminated colour A4 print outs (Appendix 8-3,4,5).

7.2.4 Procedure

Participants were first screened for knowledge of share trading to ensure only novices were used. All participants also confirmed that they possessed no serious visual impairment and had normal colour vision (Appendix 5-4).

At the start of the experiment, an overall explanation of the concept and task were given on screen, which participants were able to work through at their own pace. Once these had been understood, the training session commenced.

The training session featured exactly the same type of questions as those which would feature in the main experiment. The only difference was that these were not randomised and designed to become progressively more difficult. If a wrong answer was given, then an explanation screen appeared (Appendix 8-15) explaining why the answer given was incorrect and how the correct answer should be reached. A question of a similar type but featuring different values was then automatically inserted into the 'question queue'

Each question itself consisted of two screens: a 'Question' screen and a 'Answer' screen. The Question screen showed the question only, while the Answer screen showed the question and the three pictorial answers (Appendix 8-11). Participants were asked to read the question and once it was understood, click a 'reveal' button to show the potential answers. In this manner it was intended that an idea of the question answering strategy adopted by participants in each condition could be obtained.

The training session did not end until 10 questions covering the full range of question types had been answered correctly. Once this had been achieved, the experimental session commenced automatically. This was split into four parts each containing the 24 questions which were presented in a randomised order. At the start of the experimental session it was emphasised that each question should be answered as quickly as possible without any errors being made. During the experimental session itself participants were not told the individual result of each question – however a score was given (out of 24) at the end of each part. After each part had been completed participants were given a few minutes rest. Once the four experimental sessions had been completed, the overall experiment was at an end.

A Flow Diagram featuring the different conditions is shown on the next page. Each of the four representation conditions is represented by a column of boxes. Each box represents one part of the test (or group of 24 questions). Within each box (or part) are three divisions labelled '1', '2' or '3'. These divisions represent the different question complexity conditions, which were present in each part. Finally. In the magnified diagram below, a box is shown with eight miniature boxes in each division. These represent individual questions and are divided into two halves (one white and one plum coloured). These halves represent the different 'screen' conditions (Question screen vs. Answer screen), which were present in each question. In this way it can be seen how the different within and between subject conditions were related to each other.

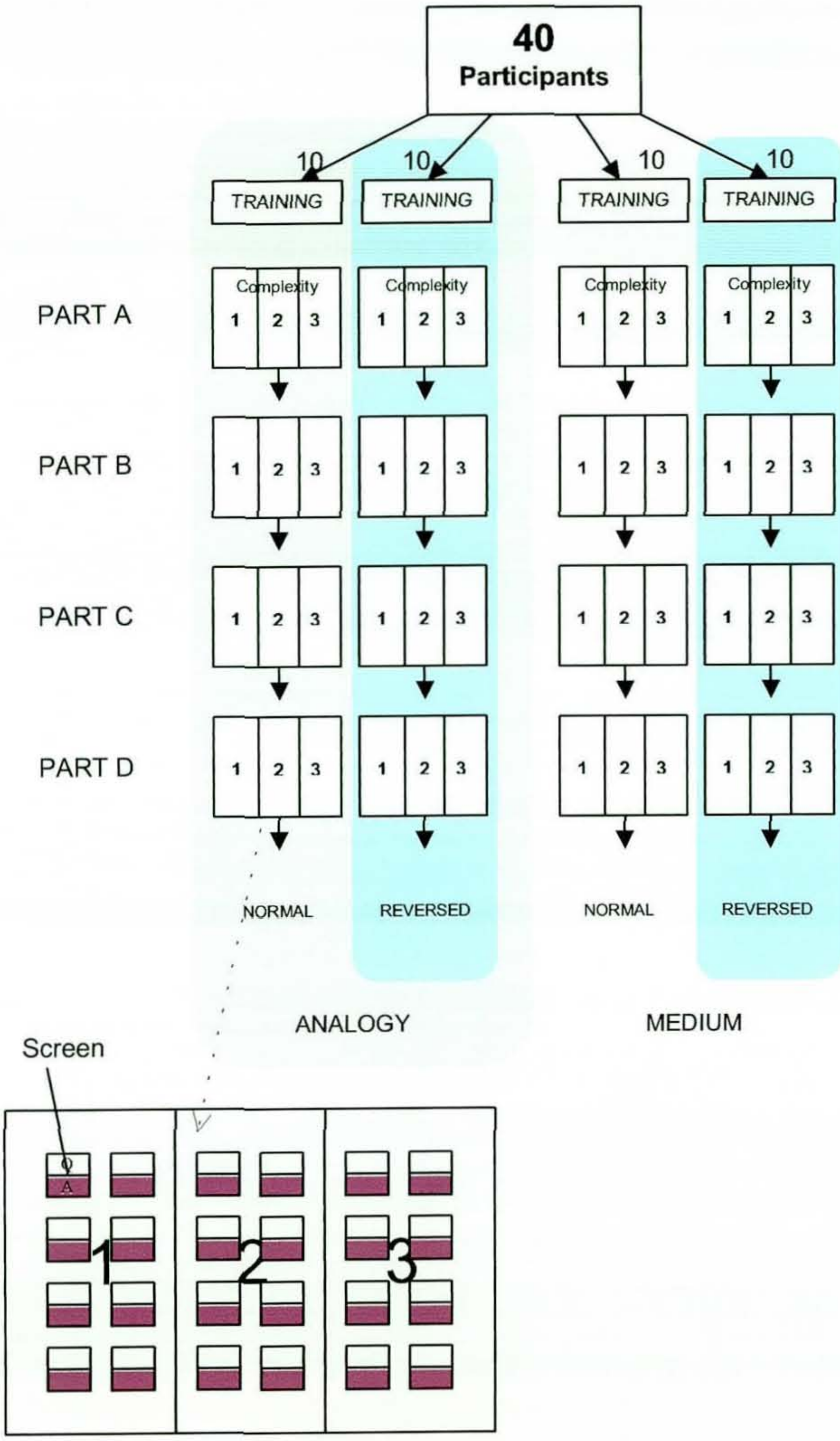


Figure 7-3 – Flow Diagram of Conditions in Experiment 5

7.3 Results

Measurements collected in the experiment related to time per question and accuracy of each question. These were split over 2 between subject variables and 3 within subject variables. The two between subject variables were:

- Representation Condition (High Analogy [Container] / Low analogy [wall])
- Representation Directionality (Normal / Reversed)

The three within subject variables were:

- Screen (i.e. 'Question' screen & 'Answer' screen use)
- Part (i.e. first, second, third, or fourth quarter of the experiment)
- Question Complexity (i.e. Number of variables [1,2 or 3] featuring in the question)

These were analysed using a repeated measures factorial ANOVA on SUPERANOVA™ a statistics program which specialises in the calculation of ANOVAs. Each category of question was repeated four times, with the mean of these being used in the statistical calculation. A log transformation was then performed on these times, given the fact that there was a degree of negative skew when the times were displayed as a histogram. The only measurements used were those of the correct questions. Incorrect questions were disregarded, and the mean of the other questions of that type for that participant substituted. While this may lead to some bias, it was preferred to the method of including 'incorrect' times in a sensitive reaction time context. The results were actually calculated using both methods, revealing that there was no change in any of the significance level bands. The results reported here however do not include incorrect answers.

The complexity of the results means that the reporting format used here is the reverse of that used in previous experiments. The results of the ANOVA are presented first, followed by the exploratory data and post-hoc analyses of the effects of interest. In this manner the many effects can first be seen in the context of one another, before being isolated and discussed in further detail.

7.3.1 Time

The ANOVA generated has been split into a series of smaller tables to aid clarity. These are categorised in terms of the different variables of interest.:

Analogy & Directionality

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
ANALOGY	1	1.433	1.433	1.375	0.2486
DIRECTIONALITY	1	18.985	18.985	18.217	**<u><0.01</u>**
ANALOGY*DIRECTIONALITY	1	3.575	3.575	3.431	0.0722
Subject (Group)	36	37.519	1.042		

Table 7-1: Table of ANOVA Relating To Analogy & Directionality

The most important variables of the experiment were those of Analogy and Directionality. Analogy refers to the type of representation used (i.e. Container or wall) and Directionality refers to the direction of the mappings (i.e. Whether UP=MORE vs. DOWN=MORE). It can be seen from the ANOVA that Directionality is significant but Analogy is not. The interaction of the two is also insignificant.

Screen

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
Screen	1	24.552	24.552	34.408	**<u><0.01</u>**
ANALOGY * Screen	1	9.648	9.648	13.521	**<u><0.01</u>**
DIRECTIONALITY * Screen	1	12.916	12.916	18.100	**<u><0.01</u>**
ANALOGY*DIRECTIONALITY* Screen	1	1.217	1.217	1.705	0.1999
Screen* Subject (Group)	36	25.689	0.714		

Table 7-2: ANOVA Results Relating To Screen

Screen refers to the difference in time spent between the 'Question' Screen, (where only the questions were visible) and the 'Answer' Screen, where both the questions and answers were visible. While Screen on it's own is not of interest, the interactions between Screen and the other variables are. Notably, Analogy*Screen and Directionality*Screen are significant here.

Parts

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
Parts	3	2.798	0.933	23.671	**<u>≤0.01</u>**
ANALOGY * Parts	3	0.474	0.158	4.014	**<u>≤0.01</u>**
DIRECTIONALITY* Parts	3	0.162	0.054	0.374	0.2547
ANALOGY*DIRECTIONALITY * Parts	3	0.664	0.221	5.617	**<u>≤0.01</u>**
Parts* Subject (Group)	108	4.255			

Table 7-3: ANOVA Results Relating To Parts

The 96 questions were presented in four sessions (or parts) of 24 questions in between which subjects were given a short rest. The variable 'Parts' gives an indication of the difference in time taken to complete each part of the test. As such it is a measure of learning and, not surprisingly, it is highly significant. The interactions are of more interest, and here it can be seen that there is a significant interaction between Analogy and learning, as well as a three way interaction of Analogy * Directionality and learning.

Complexity

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
Complexity	2	6.068	3.034	104.574	**<u>≤0.01</u>**
ANALOGY * Complexity	2	0.167	0.084	2.880	0.0626
DIRECTIONALITY * Complexity	2	0.211	0.105	3.635	**<u>≤0.01</u>**
ANALOGY*DIRECTIONALITY *Complexity	2	0.032	0.016	0.551	0.5785
Complexity* Subject (Group)	72	2.089	0.029		

Table 7-4: ANOVA Results Relating To Complexity

'Complexity' refers to the number of variables referred to in a question (whether this was 1, 2 or 3). Not surprising this has an effect on time taken. Complexity has also interacted with Directionality, meaning that the direction in which the mappings are oriented (e.g. UP=MORE) had an effect on participants' ability to answer more complex questions.

Additional Complex Interactions

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
ANALOGY * SCREEN * Parts	3	0.839	0.280	7.694	**<0.01**
DIRECTIONALITY * SCREEN * Parts	3	0.273	0.091	2.501	0.633
ANALOGY * DIRECTIONALITY * SCREEN* Parts	3	0.016	0.005	0.144	0.9336
SCREEN* Parts*Subject (Group)	108	3.927	0.036		
ANALOGY * SCREEN * Complexity	2	0.079	0.040	1.616	0.2058
DIRECTIONALITY * SCREEN * Complexity	2	0.183	0.091	3.720	0.290
ANALOGY * DIRECTIONALITY * SCREEN * Complexity	2	0.022	0.011	0.456	0.6358
SCREEN * Complexity * Subject(Group)	72	1.768	0.025		
ANALOGY * Parts * Complexity	6	0.081	0.013	1.038	0.4013
DIRECTIONALITY * Parts * Complexity	6	0.149	0.025	1.924	0.0782
ANALOGY * DIRECTIONALITY * Parts*Complexity	6	0.037	0.006	0.476	0.8257
Parts * Complexity * Subject(Group)	216	2.797	0.013		
ANALOGY * SCREEN * Parts * Complexity	6	0.047	0.008	0.601	0.7293
DIRECTIONALITY * SCREEN * Parts * Complexity	6	0.079	0.013	1.010	0.4194
ANALOGY * DIRECTIONALITY * SCREEN * Parts * Complexity	6	0.059	0.010	0.750	0.6101
SCREEN * Parts * Complexity * Subject(Group)	216	2.825	0.013		

Table 7-5: ANOVA Results For Complex Interactions

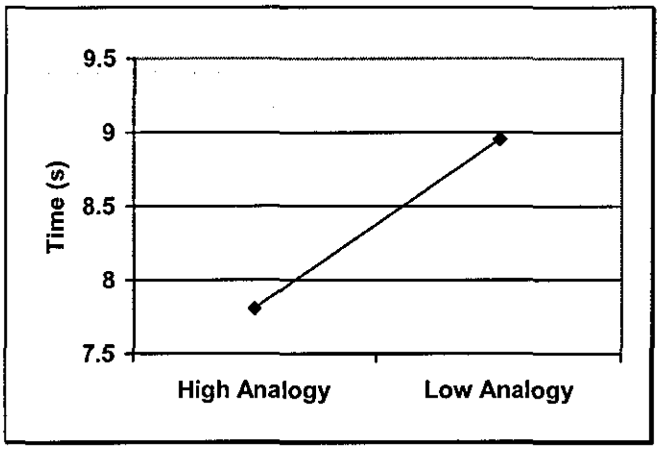
The remaining, more complex interactions are grouped together in Table 8-5. One of these is significant, namely Analogy*Screen*Parts

In summary the significant results of the ANOVA, which are of interest, applied to:

- Analogy * Screen
- Analogy * Parts
- Analogy * Directionality * Parts
- Analogy * Screen * Parts
- Directionality
- Directionality * Screen
- Directionality * Complexity

These will now be explored in more detail:

Analogy



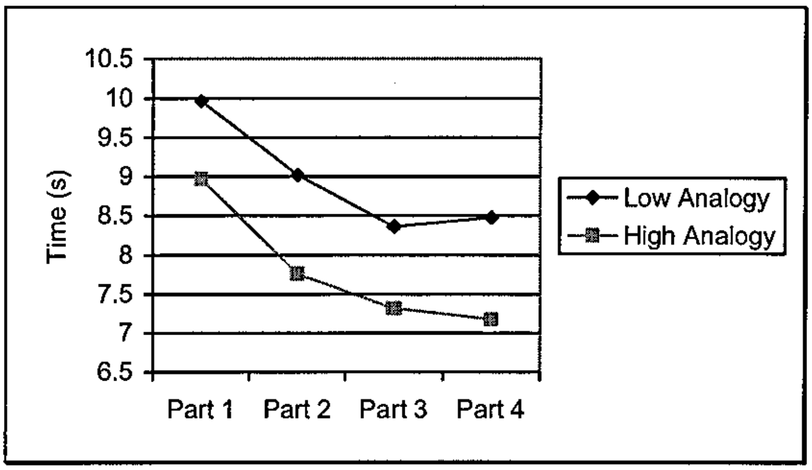
Graph 7-1: Main Effect of Analogy Level on Mean Decision Times in Experiment 5

	Count	Mean	Std. Dev	Std. Error
High Analogy	480	7.806	4.704	0.215
Low analogy	480	8.955	6.196	0.283

Table 7-6: Means Table of Analogy & Directionality Times in Experiment 5

Despite the differences in mean shown in the graph, the effect of analogy level ($F[1,36]=1.375$, $p=0.248$) on decision time was not significant. This was one of the primary questions which the experiment was designed to answer. Nevertheless, there were a number of other interactions in the experiment which suggest that the effect of analogy level is complex. These are expanded upon in due course.

Analogy Level & Parts (Learning)



Graph 7-2: Interaction Plot of Analogy Level & Parts Reaction Times in Experiment 5

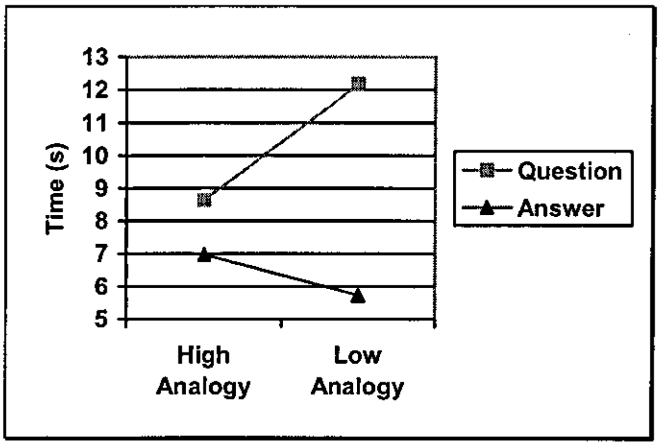
	Count	Mean	Std. Dev	Std. Error
Part 1, High	240	8.967	5.478	0.354
1, Low	240	9.964	7.992	0.516
2, High	240	7.761	5.428	0.350
2, Low	240	9.020	6.964	0.450
3, High	240	7.318	5.077	0.328
3, Low	240	8.360	5.669	0.366
4, High	240	7.177	5.009	0.323
4, Low	240	8.475	6.838	0.441

Table 7-7: Means Table of Analogy Level & Part Times in Experiment 5

The graph shows an interesting and significant interaction ($F[3,108]=.4.014$, $p<0.01$). In the low analogy condition, an asymptote appears to be reached sooner and more markedly than in the High Analogy condition. In fact in the High Analogy condition it appears that the asymptote had not yet been reached, and that further practice may lead to even quicker times. The high analogy representation therefore appears as quicker than the low analogy condition but takes longer to learn to use at its 'optimum' performance level. It may be therefore that were the experiment longer, a significant main effect of analogy level may have been found.

Analogy Level & Screen

An interesting interaction which was significant ($F[1,36]=13.52$, $p<0.01$), was that of Analogy Level & Screen:



Graph 7-3:Interaction Plot of Analogy Level & Screen Reaction Times in Experiment 5

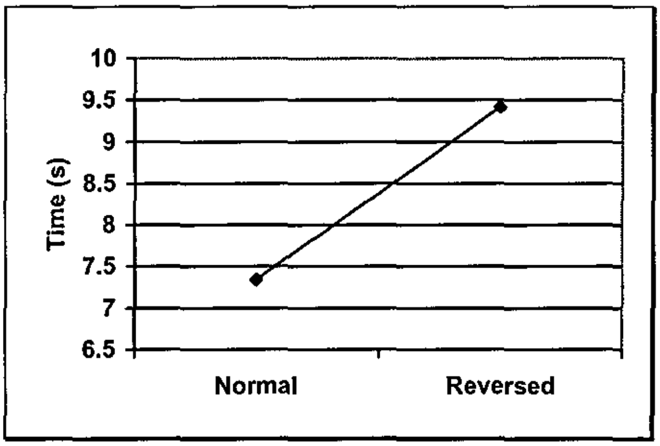
	Count	Mean	Std. Dev.	Std. Error
Question, High Analogy	240	8.644	4.675	0.302
Question, Low analogy	240	12.175	5.859	0.378
Answer, High Analogy	240	6.967	4.590	0.296
Answer, Low analogy	240	5.734	4.668	0.301

Table 7-8: Means Table of Analogy Level & Screen Reaction Times in Experiment 5

The interaction plot shows that the 'Answer' times here were actually longer in the High Analogy condition than in the Low analogy condition ($F[1,36]=13.521$, $p<0.01$). This has interesting implications as it indicates that participants used different strategies to complete the task depending on the experiment condition they were in. Participants in the Low analogy condition therefore appeared to spend longer viewing the question alone, and then viewed the answer screen for only a short time before choosing the answer. In the high analogy condition on the other hand, less time was spent viewing the question alone and more time viewing the answer. It seems therefore that participants in the high analogy condition were using the answer representations as an actual aid to helping them arrive at the correct answer, while the Low analogy representations were not used in this way.

Directionality

The effect of directionality on reaction time is the most predominant ($F[1,36]=18.217$, $p<0.01$) in the experiment.



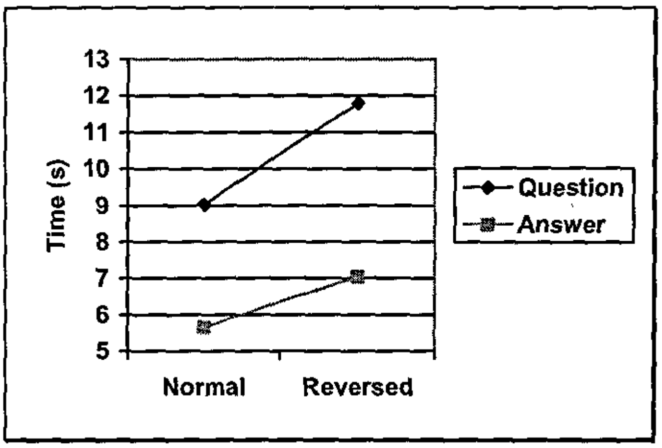
Graph 7-4: Main effect of Directionality on Reaction Time in Experiment 5

	Count	Mean	Std. Dev	Std. Error
Normal	480	7.339	4.213	0.192
Reversed	480	9.421	6.424	0.293

Table 7-9: Means Table of Directionality Times in Experiment 5

Participants using the reversed representations (E.g., UP=LESS) took significantly longer than those using representations which used the traditional mapping direction. This effect has also produced a number of interactions with other variables in the experiment.

Directionality & Screen



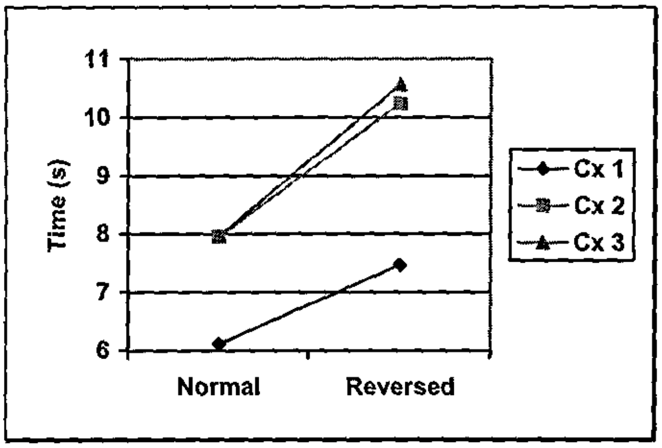
Graph 7-5: Interaction Plot of Directionality & Screen Mean Reaction Times in Experiment 5

	Count	Mean	Std. Dev	Std. Error
Normal, Question	480	0.742	0.298	0.014
Reversed, Question	480	1.105	0.201	0.009
Normal, Answer	480	0.680	0.247	0.011
Reversed, Answer	480	0.715	0.324	0.015

Table 7-10: Means Table of Directionality & Screen Times in Experiment 5

The significant ($F[1,36]=18.1$, $p<0.01$), interaction between directionality and screen shows that time spent on the 'Question' screen was disproportionately higher in the more difficult 'reversed' condition than in the normal condition. In the more difficult 'reversed' condition therefore it seems that participants needed to spend longer reading the question than in the easier 'normal' condition. This may have something to do with qualitatively differing answering strategies (as is likely in the Analogy Level* Screen interaction), or it may be that the more difficult representations required the question to be effectively committed to memory before the answers could be seen (a task that would take more time).

Directionality & Complexity



Graph 7-6: Interaction Plot of Directionality & Complexity Reaction Times in Experiment 5

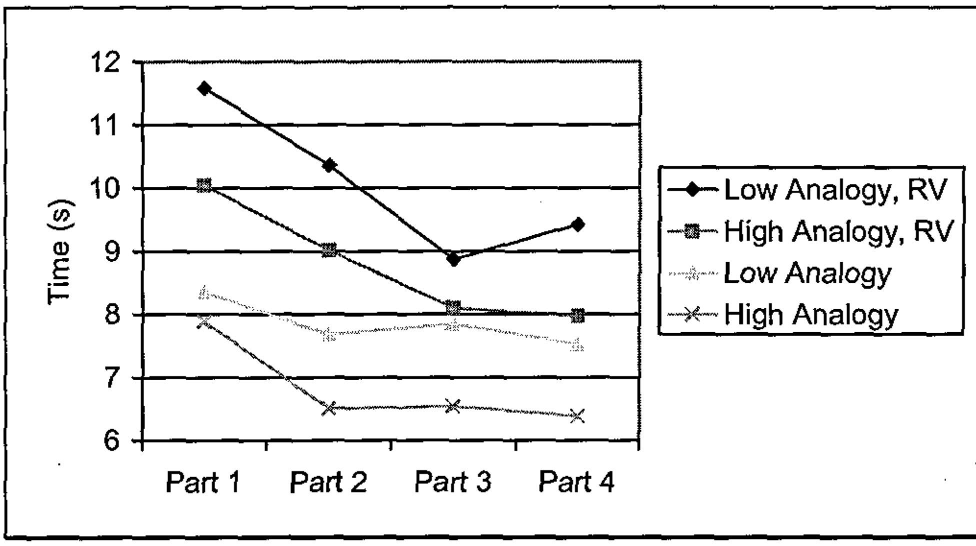
	Count	Mean	Std Dev.	Std. Error
Cx1, Normal	160	6.106	3.382	0.267
Cx1, Reversed	160	7.469	4.782	0.378
Cx2, Normal	160	7.953	4.404	0.348
Cx2, Reversed	160	10.239	6.706	0.530
Cx3, Normal	160	7.959	4.509	0.356
Cx3, Reversed	160	10.555	7.118	0.563

Table 7-11: Means Table of Directionality & Complexity Reaction Times in Experiment 5

The plot of directionality and complexity reaction times ($F[2,72]=3.635$, $p=0.03$) reveals a significant interaction. The gap between 2 and 3 variable questions is larger in the more difficult condition than in the normal condition. One explanation for this is that the more difficult reversed condition imposes an extra cognitive load which makes the already difficult 2 and 3 variable questions even more difficult.

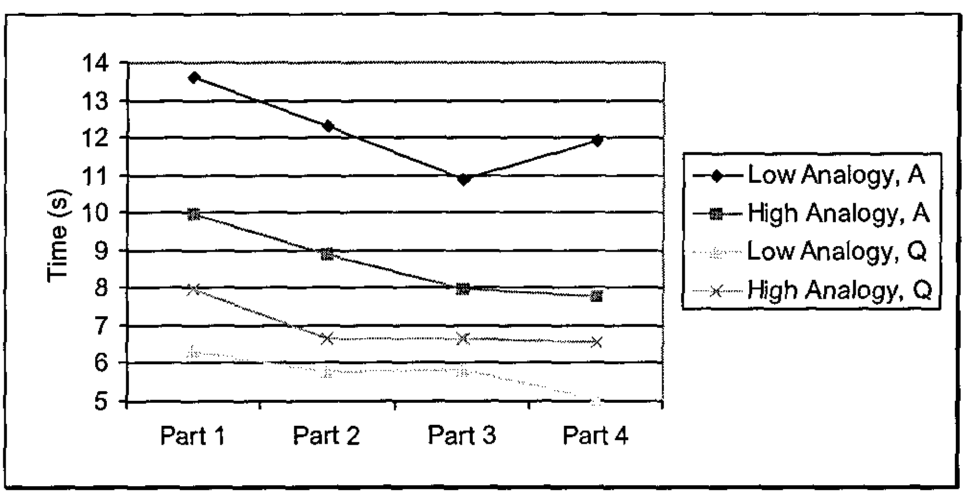
Complex Interactions

This complex interaction produced a significant result ($F[3,108]=18.1$, $p<0.01$).



Graph 7-7: Interaction of Analogy Level*Directionality*Parts

It is difficult however to propose a reliable explanation regarding the cause of this interaction, given the complexity of the variables involved.



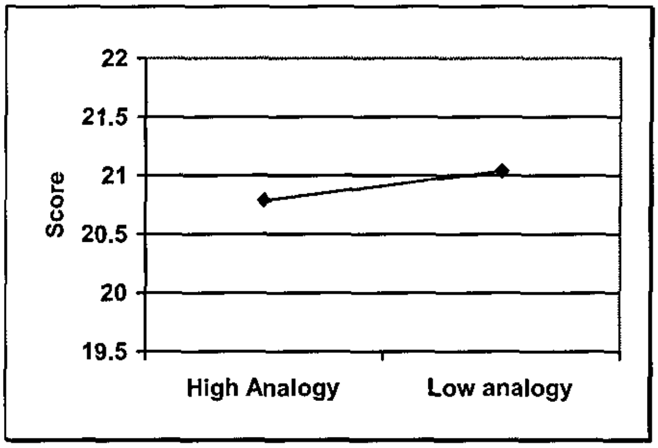
Graph 7-8: Interaction of Analogy Level * Screen * Parts

Again, in the case of Analogy Level*Screen*Parts, it is difficult to propose a reliable explanation of the significant result. Although one contributing factor to the significant difference may be that the time spent on the answer screen in the low analogy condition has increased for the last part of the experiment. It may potentially be that the task strategy was changing to become more akin to that used in the high analogy condition.

7.3.2 Accuracy

Scores out of a maximum of 27 were collected for each participant. The nature of this data meant that parametric tests were inappropriate. The limited nature of non-parametric tests which do exist also mean that the data with regard to accuracy are less detailed than those used for time, and could not extend to interactions for example. Nevertheless, a broad picture of the accuracy data could still be obtained across the independent variable conditions of Analogy Level and directionality.

Effect of Analogy Level



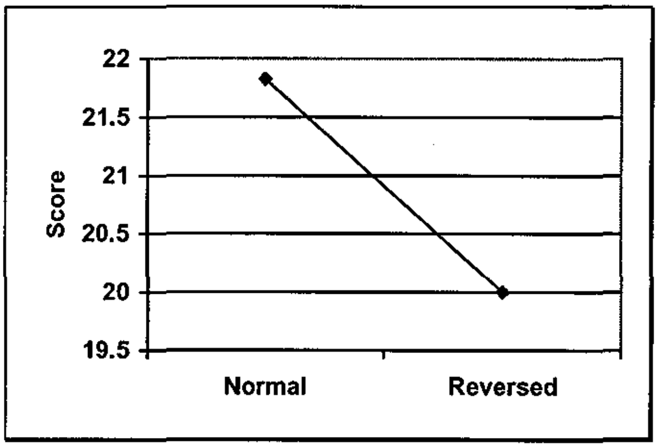
Graph 7-9: Plot of Mean Score (Max=24) Per Analogy Level Condition in Experiment 5

Mann Whitney test	
P value	0.7250
Sum of ranks in column A,B	423.5 , 396.5
Mann-Whitney U	186.5

Table 7-12: Table of Mann-Whitney Results On Effect Of Analogy Level on Errors in Experiment 5

A plot of the means in each analogy condition shows that the mean error rate per participant is higher in the Low analogy condition. The Mann-Whitney U Test however shows that this difference is not significant.

Effect of Directionality



Graph 7-10: Plot of Mean Score (Max=24) per Directionality Condition in Experiment 5

Mann Whitney test	
P value	0.0045
Sum of ranks in column A,B	304.5 , 515.5
Mann-Whitney U	94.50

Table 7-13: Table of Mann-Whitney Results On Effect Of Directionality on Errors in Experiment 5

A plot of the means in each directionality condition shows that the mean error rate per participant is higher in the reversed condition. The Mann-Whitney U Test reveals that this difference is indeed significant.

7.4 Discussion

There were three main aims to this experiment:

- To investigate if visual analogy level leads to a difference for task effectiveness in terms of speed, accuracy and learning rate
- To examine if directionality interacts with level of analogy with regard to task effectiveness
- To examine if analogy level leads to a difference in task strategy adopted

These will now be dealt with in turn.

7.4.1 Visual Analogy & Effectiveness

The key question of the experiment concerned the effect of visual analogy level on task performance. It was expected that the 'high' analogy representation (the container) might lead to better performance in terms of time, accuracy and speed of learning. It turned out that while average times were faster and the average number of mistakes was lower in the high analogy condition, this trend was not significant.

There are a number of possible explanations for this. Dealing first with the differences in accuracy scores between the two conditions, participants were asked to complete the task as quickly as possible without making any mistakes – so this is actually a result which should be expected.

In terms of the speed with which the tasks were completed, it may be that the difference between the representations was simply not great enough for any time difference to become apparent. Had the 'low' analogy representation been even more distant in terms of the level of analogy present in the representation (e.g. the metal balls were coloured blue, yellow and pink instead of gold, silver and bronze) then a significant difference may have been seen which would have provided some evidence for helpfulness of visual analogy.

In terms of learning rate, it actually appears that the asymptote or fastest performance level was reached more quickly in the 'low' analogy condition than the 'high' analogy condition. One interpretation of this is that the 'low' analogy condition actually leads to faster learning. However, it should be borne in mind that the asymptote for the 'high' analogy condition appears to lie at a faster speed than in the 'low' level condition. In addition, it also appears that the learning was still continuing in the 'high' analogy condition even in the last 24 of the 96 questions. It therefore seems that once an asymptote is reached, the 'high' analogy condition may well lead to faster times. An important aspect nevertheless is that this peak is not easily reached.

7.4.2 Visual Analogy & Directionality

The overall effect of directionality on task effectiveness was the most marked in the whole experiment. This is to be expected however. Of more interest was the *interaction of analogy level with directionality. In other words – was 'high' analogy* representation performance affected more than 'low' analogy representation performance when the mappings were reversed? The results reveal that this does not appear to be the case, with the interaction value not even approaching significance. If the directionality is reversed, participants therefore clearly find it very hard to complete the task regardless of the representation used. The increased level of real world knowledge in the 'high' analogy representation is not more adversely affected, though, than the 'low' analogy representation where less explicit information regarding the concept was present.

It may have been the case that this experiment would have produced suggestive evidence for the formation of mental models through the disproportionate degradation in performance in the High Analogy condition when the directionality is reversed. The occurrence of such an effect may have suggested that there is some understanding fostered by the higher level of analogy which is compromised when the meaning of this analogy is purposefully disrupted, however it was not seen here. This is most likely due to the fact that conceptual *understanding was not necessary to complete the tasks in the experiment.*

7.4.3 Visual Analogy & Task Strategy

An interesting finding of the experiment was that analogy level appears to have lead to a different question answering strategy being followed. The table of means indicates that while the overall times in the High analogy condition were quicker, participants spent more time viewing the potential answer representations. Clearly there was a facilitative effect of doing this. It would seem that the answer representations in the High analogy (container) condition act as an effective visual aid in a way that the Low analogy (wall) representations do not.

While it is not possible to definitively explain why this was, it can be proposed that more extensive use was made of the actual question representations themselves in the 'high analogy' condition to arrive at the answer, while these were used less in the 'Low analogy' condition.

How could the representations be used "extensively" to arrive at the answer? One explanation is that participants parsed the questions to extract individual variables of the 'ideal company' (e.g. High Value needed = Gold Balls should be shown). Having done this, the variables in the visual representations displayed could then be compared for a match, and non-fitting representations eliminated. The process could then be repeated with the representations that matched, until the correct representation was identified or it was established that none fitted. This was a relatively low effort strategy as only one aspect needed to be maintained internally at one time, while the representations themselves performed part of the work by displaying what was available in an easily accessible way. It would however involve a constant re-referring to the question representations shown.

This strategy did not seem to work so well in the 'Low analogy' condition on the other hand. It appears here that the main strategy adopted was to read the question and construct the ideal answer representation internally. The complete internal construction could then be compared in one step with those shown. This involved more effort in that an entire answer had to be constructed 'in the head', but less effort in the sense that the representations shown did not have to be searched several times for individual variables. Assuming that this was the process followed, then the argument could be made that the 'high' analogy representation made the external searching (e.g. for high value) easier, while in the lower analogy representation, it was simply more effort to keep remembering what aspect represented high value, medium package size, etc. A more convenient strategy then was to perform the remembering aspect once only (while constructing the entire 'ideal answer' representation), and then comparing this in its entirety with those shown. This explanation fits the results shown in that the question 'representations' were viewed longer in the high analogy condition, as they were constantly referred to, and less in the Low analogy condition, as they were only referred to for a comparison with the already constructed mental image. Viewing the question representations while constructing this internal image, would likely have interfered with the internal construction process, explaining why the question representations were kept hidden for longer.

The role of the 'help' card in all this is unclear. It is highly likely that it was used, almost certainly to help construct the complete 'internal' answer in the Low analogy condition, and possibly to help with identification in the 'high analogy' condition. It was clear from informal observation that some participants used the help card as part of a question answering system in conjunction with the potential answer representations, while others did not use the card at all, but still memorised the mappings using the answer representations as part of their strategy. A third group did not use the answers at all, but created the answers internally (usually with the aid of the help card but not always). Exactly how help information was used is still unclear at this stage, but an interesting candidate for further exploration.

7.4.4 Experimental Issues

This is the most complicated of the experiments carried out so far, both in terms of programming logistics as well as results. The administration of the experiment itself is fairly robust as it was administered automatically. One point worth discussing was the decision to inform participants of their scores at the end of each part of the experiment. One possibility was not to inform them at all, while the other would have been to inform them at the end of every question. It was felt that informing after the end of every question would have interrupted the fluidity of the experiment as well as causing excessive examination of each decision made, thereby masking any fragile differences which the different representation types may have given rise to. On the other hand not informing participants of their score at any time during the experiment may have lead to a lack of motivation, not desirable in a 96 question experiment. It was therefore felt that the provision of a score after every 24 questions struck an appropriate compromise.

7.4.5 Design Implications

The most striking result of this experiment in terms of design implications is that reversing directionality has a highly negative effect on task performance regardless of representation used. Doing so has more important implications than incorporating explicit analogies, it should therefore always be ensured when designing multidimensional icons that directionality of variables which may be consulted is never compromised in order to incorporate a higher level visual analogy, which may seem fitting.

In terms of other design guidelines which it is possible to derive from this experiment – it can be proposed that as much scope as possible should be provided to allow for use of analogical representations as external aids to cognition. In this experiment, it was apparent that participants used the 'question' representations as external aids to arrive at answers. The ability to do this should be facilitated.

The results of this experiment do not allow much more in the way of design guidance to be generated however. The use of visual analogy as a guiding theory of design has not received overwhelming support from the results. More can most likely be said after an extended examination of the subject in the context of the next experiment.

7.4.6 Summary

The experiment has not revealed any significant effect of visual analogy level with regard to improving task performance. A difference was seen however in terms of learning, with representations featuring a high level of visual analogy actually requiring longer for the optimum level of performance to be reached, although this level was then faster than the optimum level for the Low analogy condition. When reversing directionality, a marked decrease in performance was witnessed, however this did not interact with level of analogy. It has also been shown that the use of analogical representations appears to lead to the adoption of a qualitatively different strategy of external cognition.

There are a number of findings from this experiment, which raise interesting issues for further investigation. These include the question of analogy level – Was no clear performance facilitation found because the difference between representations was not great enough? A second question concerns the question of strategy, namely whether a more precise idea of strategy difference can be gained by systematically monitoring the use of external resources, (i.e. the help card). The next experiment will investigate these issues.

Chapter 8 - EXPERIMENT 6

The previous experiment revealed a number of findings, which are worthy of further exploration. These concerned the fact that no significant difference was found with regard to analogy level and task effectiveness (although the trend was suggestive of this). Another fact that became apparent was that participants used different strategies to answer the questions, depending on whether the 'high' or 'low' analogy representations were being used.

The previous experiment also allowed no idea to be gained of the role the semantic connotations of the representations played when wrong answers were made. It may have been the case that the semantic prompting of the representations caused people to err in systematic ways. No record of errors was made however, so it was not possible to investigate this. One goal of this experiment will be to examine the identity of the mistakes.

These areas will now be described in more detail, incorporating a description of how this experiment will be designed to answer them.

8.1.1 Visual Analogy Level & Task Effectiveness

In the previous experiment the two representations used to compare analogy level were the 'high' analogy representation (container) and the 'medium' representation (glass wall). These were chosen as it was felt that they provided a suitable platform to illustrate how two representations which are visually similar, can be more distinct from each other in terms of meaning – which might make a difference with regard to task effectiveness. No broad significant difference in task effectiveness was observed however, although there were suggestive effects. This experiment therefore aims to broaden the difference between the two representations used by using the 'high' analogy representation once more, but replacing the 'medium' (wall) analogy with the 'low' analogy (cylinder) representation (It should be re-emphasised here that the 'medium' analogy representation was referred to as 'low' analogy throughout the last experiment for comparison purposes). The cylinder representation can be distinguished from the container (high) and glass wall (medium) representations as it does not provide additional information in the form of visual prompts for value (represented by metals of different values), packages (balls) and a company (glass). Instead the qualitative differences between these variables are hidden within the height, width and diameter dimensions of a cylinder. (See Chapter 4 for a more complete discussion). As the task to be carried out (which is similar to that in the previous experiment) requires identification of variables and their current level, the high analogy (container) representation should theoretically enhance performance in comparison to the low analogy (cylinder) representation through virtue of the fact that it provides additional visual prompts for this information. Whether this is actually the case is a key question in this experiment.

8.1.2 Visual Analogy Level & Strategy

The previous experiment also revealed that different strategies were used depending on whether a high analogy or low analogy representation is used. It was proposed that the question representations themselves were being used to answer the questions in the high analogy condition, while in the low analogy condition, it was proposed that the answers were generally constructed internally, meaning that the presence of the representations during this process may actually have had an interfering effect. An additional aspect to this explanation however is the key card, which showed the various mappings. This could be used at anytime, whether the questions were being viewed alone, or whether they were viewed together with the answers. This allowed a degree of vagueness with regard to the measurements, as it was not measured exactly how the key card was used. There may therefore be aspects of this usage which can reveal more about how strategies differ in the two visual conditions.

This experiment will therefore also examine the amount of time the help card is viewed. In the previous experiment this took the form of a separate card. In this experiment the 'help' card will be incorporated into the experimental program and be viewed on the monitor. This will allow systematic measurements of its use to be taken.

8.1.3 Visual Analogy & Inappropriate Semantic Connotations

A further issue for investigation which was not able to be thoroughly investigated in the previous experiment was the effect of representation form on error. Just as an appropriate visual representation is proposed as helping correct decisions to be made, an inappropriate visual representation may well have the opposite effect, therefore systematically prompting incorrect decisions to be made. This has parallels with command-line interface research, where the use of commands making use of everyday language which at first appear helpful can actually hinder effective use due to the unwanted connotations that come with the term (Lansdale & Ormerod, 1994). The experimental program in this study was therefore enhanced to also allow the type of mistake to be investigated – specifically to see if any systematic pattern of errors could be revealed.

8.2 Summary

In summary then this experiment will take a similar form to the previous one, but will be altered slightly to focus on the following issues.

- To investigate the effect of a wider difference of analogy level on task performance
- To examine the connection between analogical visualisations and external cognition.

- To see if the errors made are systematically biased in any way by the representations

These questions will be examined by changing the design of the experiment so that the 'low' analogy is used instead of the 'medium' representation in one of the conditions. Measurements will also be taken of the use of the help card as well as of the type of errors made.

8.3 Method

EXPERIMENT 6

8.3.1 Participants

20 students at Loughborough University took part in this study, all of whom, had no experience with share dealing, and possessed normal colour vision. Ages ranged from 18-49. Each was paid £3.00 for their participation in the study. There were 2 between-subject conditions in the experiment with 10 participants taking part in each condition.

8.3.2 Task

The task in this experiment was identical to the previous experiment described in Chapter 8

8.3.3 Stimuli & Apparatus

Presentation Method

The experiment was administered once again using HyperCard™. All details of the administration program were identical to the previous experiment, with relevant instructions (Appendix 9-1,2), training programs (Appendix 9-3), and experimental programs (Appendix 9-4,5,6) all being administered automatically. There were however two important exceptions:

- The program recorded not only the fact that an error had been made, but also exactly what that error was
- The 'key' card of the previous experiment was incorporated into the experimental program. (Appendix 9-2) This allowed an exact record to be taken of the number and duration of times that help was required. The 'help' key was incorporated onto the question screen in the manner shown (circled) in Figure 8-1.

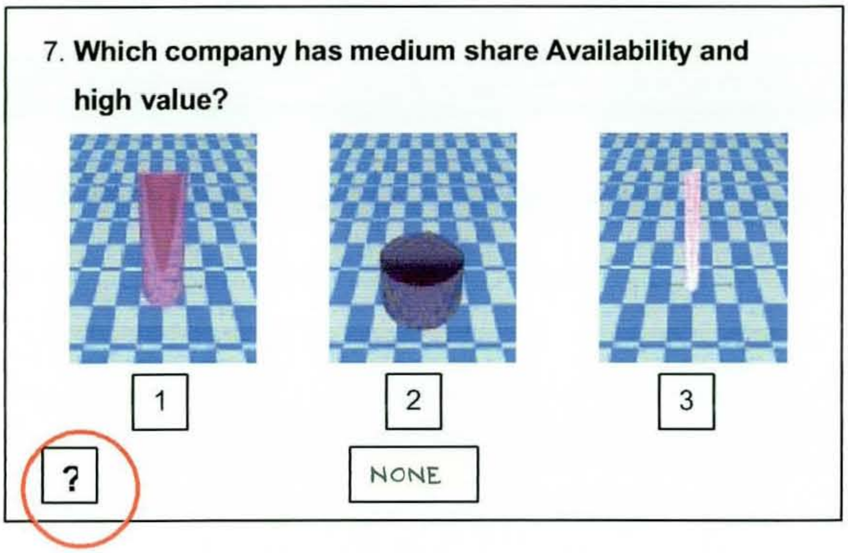


Figure 8-1: Example of Task Screen in Experiment 6

The help screen was not visible at the same time as the question screen however. This was a major difference between this experiment and Experiment 5.

Questions

The majority of the questions used in this experiment were similar to those used in Experiment 5. The results from that experiment had revealed however that there were a number of questions the meaning of which appeared as somewhat ambiguous. These questions were replaced with less ambiguous questions in this experiment (Appendix 9-8). The representations for each question were also distributed to ensure that each different type of pictorial cue featured equally in each type of question (Appendix 9-7).

Representations

The representations used in this experiment were the 'high' analogy (container) and 'low analogy (cylinder). These are illustrated in Figure 8-2 and were chosen as they feature an even greater difference in abstraction level than the representations used in the previous experiment. The 'Cylinder' condition is therefore simpler, and incorporates less relationship specific information with regard to the share concept being represented.

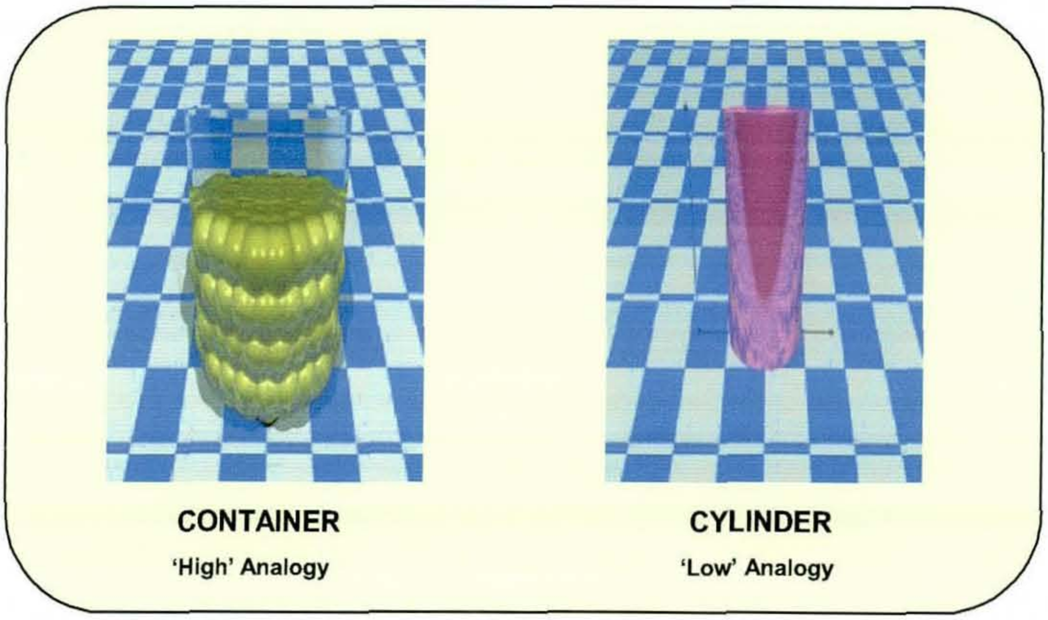


Figure 8-2: Representations used in Experiment 6

8.3.4 Procedure

The procedure in this experiment was again exactly the same as that used in Experiment 5.

8.4 Results

Measurements gathered in this experiment consisted of:

- Time spent on the 'Question' screen
- Time spent on the 'Answer' screen
- Time spent on the 'help' screen
- Accuracy of answer
- Identity of error made

While this experiment was of a similar design to that described previously in Chapter 8, there were a number of enhancements made on the basis of the experience gained from it. Chief among these was the incorporation of the help screen into the experimental program. This provides valuable data on the amount of times subjects needed to refer to it, and hence the ease with which the mappings could be remembered. Another enhancement was the enabling of the nature of any errors made to be identified in addition to noting whether the answer given was correct. This therefore allows for a clearer picture to be gained of whether confounding semantic or Iconic elementual connotations play a significant role in terms of errors made.

As in the previous experiment, error times were removed and replaced by the mean of the correct answers for similar types of question. In the time analysis, the 'help' screen times were also incorporated into the 'Question' screen times. The wisdom of this and alternative means of analysis will be expanded upon in the discussion.

8.4.1 Time

Source	Df	Sum Sq	Mean Sq	F-Value	p-Value
ANALOGY	1	575.839	575.839	4.977	**0.039**
Subject (Group)	18	2082.681	115.704		
Screen	1	3167.988	3167.988	13.022	**≤0.01**
ANALOGY * Screen	1	147.575	147.575	0.607	0.4462
Screen * Subject (Group)	18	4379.164	243.287		
Parts	3	720.067	240.022	18.500	**≤0.01**
ANALOGY * Parts	3	34.649	11.550	0.890	0.4522
Parts * Subject (Group)	54	700.623	12.975		
Complexity	2	634.566	317.283	64.227	**≤0.01**
ANALOGY * Complexity	2	39.964	19.982	4.045	**0.026**
Complexity * Subject (Group)	36	177.841	4.940		
ANALOGY * Screen * Parts	3	74.414	24.805	3.510	**0.021**
Screen* Parts* Subject (Group)	54	381.585	7.066		
ANALOGY * Screen * Complexity	2	26.715	13.357	1.862	0.1701
Screen * Complexity * Subject(Group)	36	258.294	7.175		
ANALOGY * Parts * Complexity	6	63.332	10.555	2.359	**0.035**
Parts * Complexity * Subject(Group)	108	483.155	4.474		
ANALOGY * Screen * Parts * Complexity	6	16.465	2.744	0.551	0.7679
Screen * Parts * Complexity * Subject(Group)	108	537.422	4.976		

Table 8-1:ANOVA Results Table of Times in Experiment 6

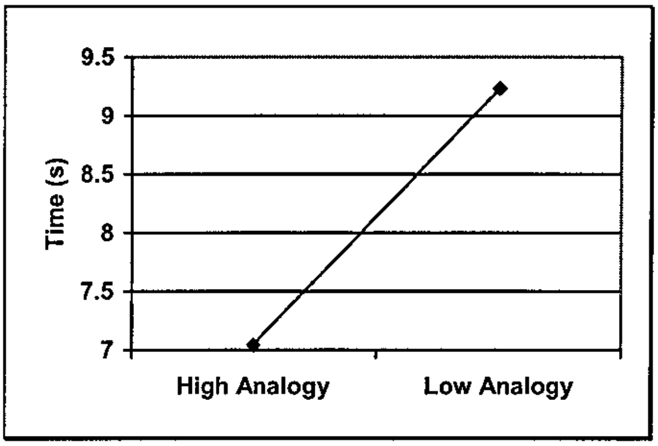
Main effects and interactions of significance which make comment on the representations are:

- Analogy
- Analogy * Complexity
- Analogy * Screen * Parts
- Analogy * Parts * Complexity

These effects will now be expanded upon in turn:

Effect of Analogy

Here it can be seen that there is a significant main effect of analogy level (F[1,18]=4.977, p=0.0386).



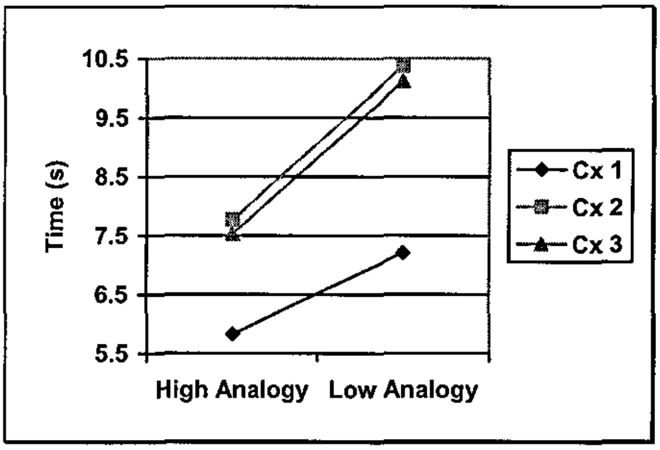
Graph 8-1: Main Effect of Analogy on Reaction Times in Experiment 6

	Count	Mean	Std. Dev	Std. Error
High Analogy	240	7.042	4.734	0.306
Low analogy	240	9.232	6.077	0.392

Table 8-2: Means Table of Analogy Times in Experiment 6

Interaction of Analogy &Complexity

The results of the ANOVA indicate that there is a significant interaction (F[2,36]=4.045, p=0.0260) of Analogy and Complexity.



Graph 8-2: Interaction Plot of Analogy & Complexity in Experiment 6

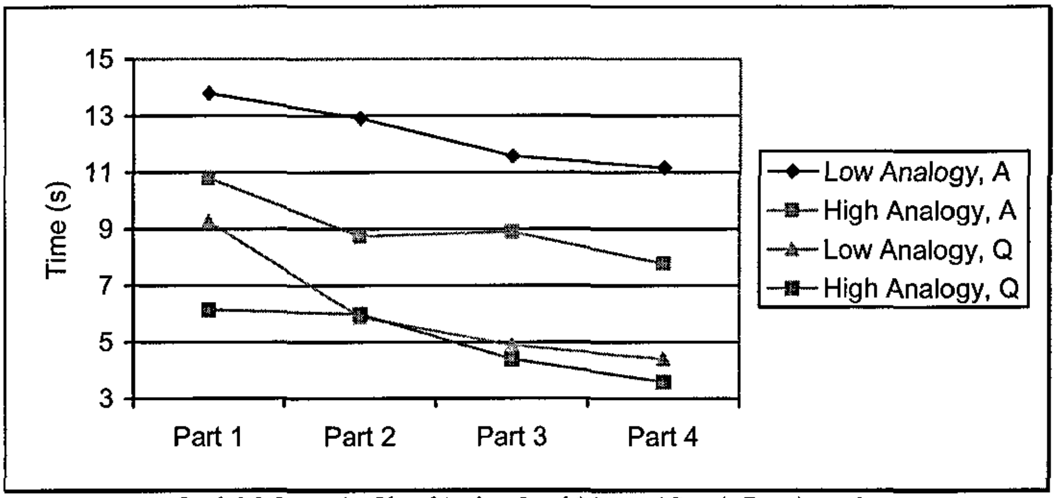
	Count	Mean	Std. Dev	Std. Error
Cx1, High Analogy	80	5.830	4.331	0.484
Cx1, Low analogy	80	7.205	4.388	0.491
Cx2, High Analogy	80	7.767	4.966	0.555
Cx2, Low analogy	80	10.374	6.530	0.730
Cx3, High Analogy	80	7.528	4.704	0.526
Cx3, Low-Analogy	80	10.119	6.599	0.738

Table 8-3: Means Table of Complexity *Analogy Level Interaction Reaction Times in Experiment 6

The more complex 2 and 3 factor questions appear to take disproportionately longer in the Low analogy condition than in the High analogy condition. Interestingly however, the supposedly more complex 3 factor questions being answered more quickly than the 2 factor questions.

Interaction of Analogy Level * Screen * Parts

The three way interaction of Analogy Level * Screen * Parts has also been shown to be significant (F[3,54]=3.510, p=0.0212).



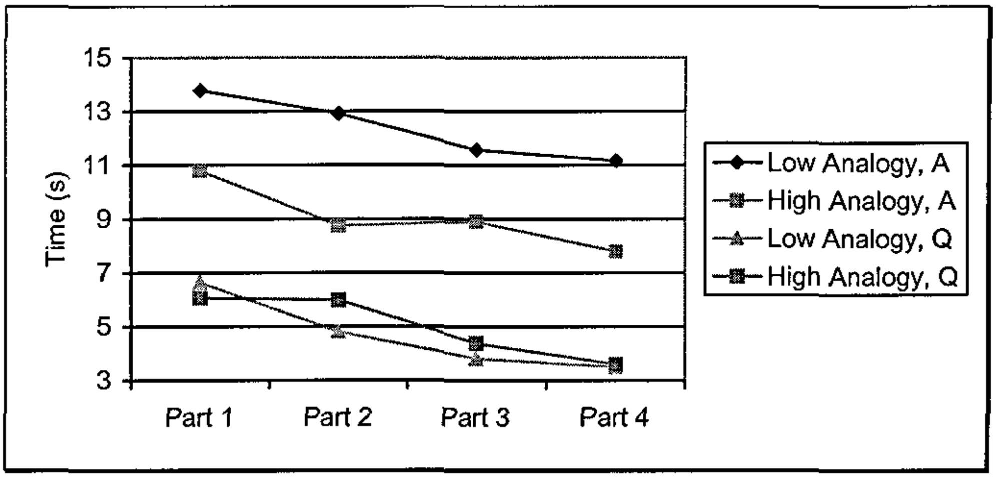
Graph 8-3: Interaction Plot of Analogy Level * Screen * Parts in Experiment 6

	Count	Mean	Std. Dev.	Std. Error
Answer, Part 1, High Analogy	30	10.801	5.833	1.065
Answer, Part 1, Low-Analogy	30	13.785	6.695	1.222
Answer, Part 2, High Analogy	30	8.745	4.783	0.873
Answer, Part 2, Low-Analogy	30	12.910	4.169	0.761
Answer, Part 3, High Analogy	30	8.896	5.074	0.926
Answer, Part 3, Low-Analogy	30	11.566	5.972	1.090
Answer, Part 4, High Analogy	30	7.784	4.487	0.819
Answer, Part 4, Low-Analogy	30	11.163	6.377	1.164
Question, Part 1, High Analogy	30	6.143	3.009	0.549
Question, Part 1, Low-Analogy	30	9.273	4.846	0.885
Question, Part 2, High Analogy	30	5.991	3.643	0.665
Question, Part 2,Low- Analogy	30	5.886	3.594	0.656
Question, Part 3, High Analogy	30	4.383	3.078	0.562
Question, Part 3, Low-Analogy	30	4.881	4.126	0.753
Question, Part 4, High Analogy	30	3.592	2.605	0.476
Question, Part 4, Low-Analogy	30	4.395	3.480	0.635

Table 8-4: Means Table of Analogy Level * Screen* Parts Interaction Times in Experiment 6

The plot reveals an interesting difference in the amount of time devoted to each activity per visual condition as the experiment progresses. There is a clear difference at the start of the experiment in the time taken for participants to read the questions (and use the help screen). This difference then disappears as the experiment progresses. There is a constant difference however between the time taken to view the potential answers, which does not change substantially as the experiment progresses.

'Question' includes the time taken to read the question and use the 'help' card while Answer equates to the time taken to view the answers –a necessary step before the answer could be given-. This was considered a convenient way to conduct the analysis and was in part a legacy from the previous experiment in which the roles were more clearly defined. The logic behind such a categorisation was that the 'Question' screen involved question preparation and the 'Answer'; part equated to question answering. Whether this division is valid is arguable especially given the range of strategies available to participants. The wide variety in use of the help screen between participants however (most of who actually used it very little) meant that it was considered the most valid approach. If the 'help' card times are taken out of the calculations then the plot appears as below:

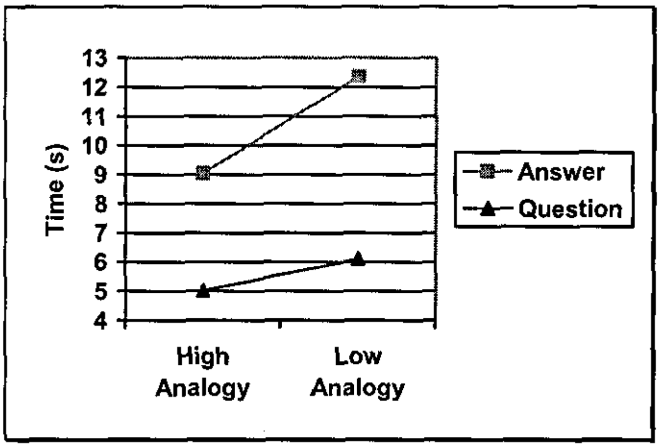


Graph 8-4 Interaction Plot of Analogy Level * Screen * Parts minus 'Help" times in Experiment 6

In this situation the interaction significance is no longer significant (F[3,54]=1.247, p=0.302). While the complexity of the interaction makes it difficult to ascertain exactly which are the most important components of the interaction, the graph would strongly suggest that this is due to Part A, in which the 'help' card appears to be heavily used in the Low-analogy condition. This interpretation would fit in well with the notion of rule learning and rule application (Kotovsky, Hayes & Simon, 1985), where rule learning equates to use of the help card, and rule application applies to time taken to view the answers before giving an answer. This interpretation is expanded upon in the discussion.

*Interaction of Analogy Level * Screen*

This was the measure in the last experiment, which lead to the conclusion that a strategy making greater use of external cognition was being adopted in the high analogy condition. In this experiment the measure was nowhere near significant (F[1,18]=0.607, p=0.4462).



Graph 8-5: Interaction Plot of Analogy Level & Screen Reaction Times in Experiment 6

	Count	Mean	Std. Dev.	Std. Error
Question, High Analogy	120	5.027	3.252	0.297
Question, Low-Analogy	120	6.109	4.430	0.404
Answer, High Analogy	120	9.056	5.124	0.468
Answer, Low-Analogy	120	12.356	5.905	0.539

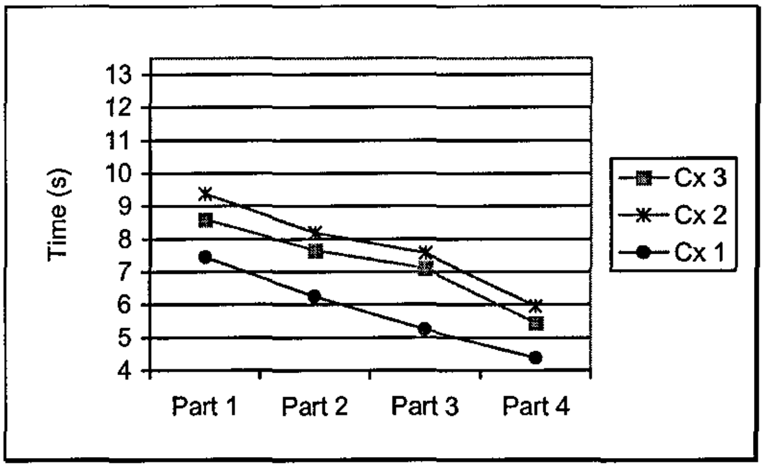
Table 8-5: Means Table of Analogy Level & Screen Reaction Times in Experiment 6

Interesting to note when the results are compared with the same figures in Experiment 5, is that the profile of results is completely different. Here Answer times are longer in both conditions, while in Experiment 5 it was Question times that were longer. Clearly, an alteration in this experiment has changed the strategy used by participants. In addition, the profile of time spent on each screen is approximately the same here across conditions, while in the last experiment they were very different.

Interaction of Analogy Level * Parts * Complexity

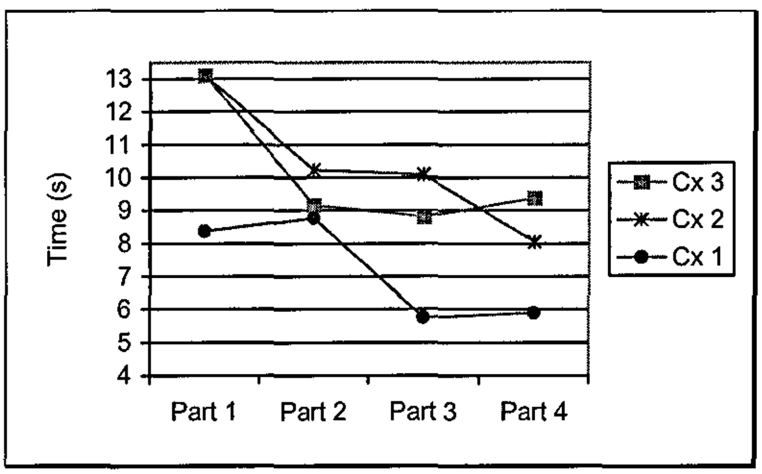
The significant interaction ($F[6,108]=2.359$, $p=0.0352$) between Analogy Level * Parts * Complexity presents an interesting if complicated picture:

HIGH ANALOGY



Graph 8-6: Interaction of Parts * Complexity in High analogy Condition in Experiment 6

LOW-ANALOGY



Graph 8-7: Interaction of Parts * Complexity in Low Analogy Condition in Experiment 6

	Count	Mean	Std. Dev	Std. Error
Part 1, Cx1, High Analogy	20	7.450	5.901	1.320
Part 1, Cx1, Low-Analogy	20	8.371	3.980	0.890
Part 1, Cx2, High Analogy	20	9.374	5.265	1.177
Part 1, Cx2, Low-Analogy	20	13.116	6.811	1.523
Part 1, Cx3, High Analogy	20	8.591	4.284	0.958
Part 1, Cx3, Low-Analogy	20	13.101	6.506	1.455
Part 2, Cx1, High Analogy	20	6.252	3.610	0.807
Part 2, Cx1, Low-Analogy	20	8.782	4.828	1.079
Part 2, Cx2, High Analogy	20	8.186	4.742	1.060
Part 2, Cx2, Low-Analogy	20	10.238	5.752	1.286
Part 2, Cx3, High Analogy	20	7.666	4.851	1.085
Part 2, Cx3, Low-Analogy	20	9.175	5.254	1.175
Part 3, Cx1, High Analogy	20	5.246	4.198	0.939
Part 3, Cx1, Low-Analogy	20	5.766	3.914	0.875
Part 3, Cx2, High Analogy	20	7.561	5.531	1.237
Part 3, Cx2, Low-Analogy	20	10.090	7.123	1.593
Part 3, Cx3, High Analogy	20	7.112	4.296	0.961
Part 3, Cx3, Low-Analogy	20	8.813	6.264	1.401
Part 4, Cx1, High Analogy	20	4.373	2.642	0.591
Part 4, Cx1, Low-Analogy	20	5.900	4.193	0.938
Part 4, Cx2, High Analogy	20	5.949	3.911	0.874
Part 4, Cx2, Low-Analogy	20	8.051	5.778	1.292
Part 4, Cx3, High Analogy	20	6.743	5.443	1.217
Part 4, Cx3, Low-Analogy	20	9.387	7.696	1.721

Table 8-6: Means Table of Analogy Level* Parts*Complexity Interaction Times in Experiment 6

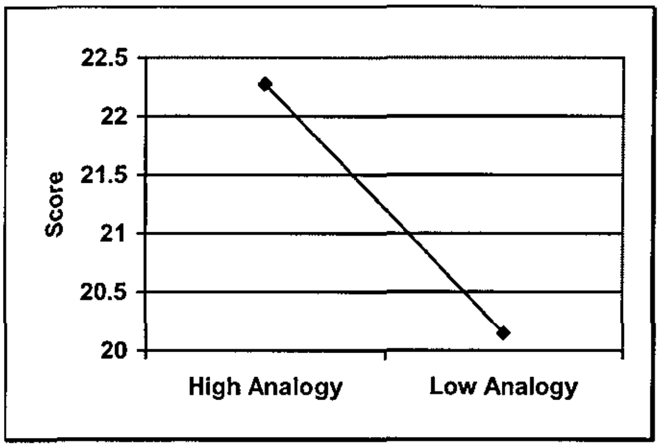
In the analogy condition, the differences between the levels of question complexity remain more or less constant, all of them decreasing by similar amounts as the experiment progresses.

In the Low-analogy condition however, the picture is completely different. The 1 factor questions are always answered most quickly, however the difference between response times fluctuates wildly as the experiment progresses. Given that the questions were identical in each visual condition, there appears to be no obvious explanation as to why this is so, although it may have something to do with different question answering strategies employed by participants in the different conditions. This will be explored further in the discussion.

8.4.2 Accuracy

A similar approach to errors was taken as in the previous experiment. Scores were taken out of a maximum of 24 for each subject and tested using the Mann-Whitney U test.

Effect of Analogy Level



Graph 8-8: Plot of Mean Score Across Analogy Levels in Experiment 6

Mann Whitney test	
P value	0.1230
Sum of ranks in column A,B	126 , 84
Mann-Whitney U	29.00

Table 8-7: Results of Mann-Whitney U Test on Accuracy Across Analogy Levels in Experiment 6

This revealed that there was no significant difference in errors made between conditions.

Error Identities

A key enhancement of this experiment is that it allowed the errors made to be identified. This therefore allows the notion of confounding semantic / Iconic elementual connotations to be identified. In the cases of both representations, one of the reasons why errors were made might have been due to the expectations (carried across from the 'real world') of what a container containing balls might mean over and above the meaning ascribed to it in the tasks here.

In order to identify if there were any systematic mistakes made, all questions were identified in which a particular inaccurate choice was made three or more times in one condition than another. A total of 10 questions were identified which fitted this description. Within each of these questions the nature of the mistake was isolated and counted to determine if a pattern emerged.

Unfortunately however this approach did not prove to be feasible. There were relatively few questions (10/96) where more than three identical mistakes had been made in any one condition. Where this was the case – it was not possible to identify systematically what aspects of the representation chosen contributed to the error, or indeed whether this was due to aspects of the other 'answer' representations in a given instance.

All the cases were in the cylinder condition however, and the vast majority referred to the representation present in the centre of the screen or Option '2' (see Figure 8-1). A Chi-Square analysis of the positions of the error representations chosen revealed that there was indeed a significant indistribution of error representation position.

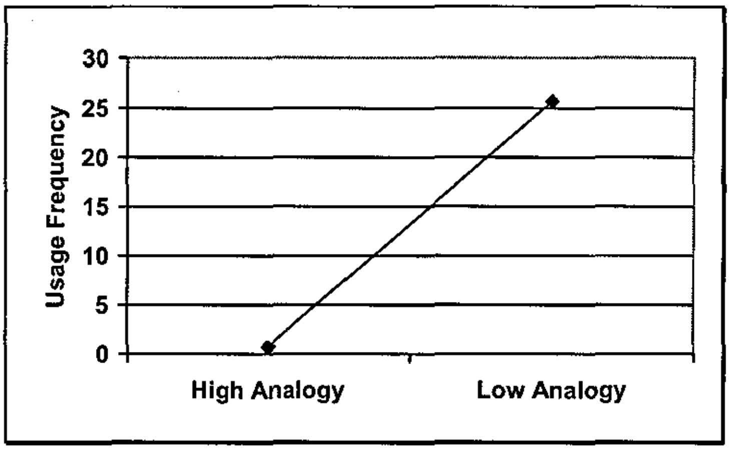
	OPTION 1	OPTION 2	OPTION 3	'None'
Actual	3	23	8	3
Expected	9.25	9.25	9.25	9.25

Table 8-8: Distribution of High Error Rate Question Error Positions in Cylinder Condition

The Chi statistic significance worked out at $p<0.01$, a highly significant figure. While it is not possible to make any substantive generalisations about this, it is likely that participants tended to choose the middle option when unsure about the answer to a particular question.

Use of The 'Help' Card

The frequencies with which the help card was used in each visual condition were counted. A graph of the means is shown below:



Graph 8-9: Graph of Mean Number of Times 'Help' Screen Used per Participant in Experiment 6

This clearly shows that there was a large discrepancy in usage between the two visual conditions. This difference was then subjected to a Mann-Whitney U Test to see if the difference was statistically significant.

Mann Whitney test	
P value	P<0.01
Sum of ranks in column A,B	70 , 140
Mann-Whitney U	15

Table 8-9: Results of Mann Whitney U Test On Help Usage Frequency in Experiment 6

This reveals that the difference between conditions is highly significant. Participants in the Low-analogy condition therefore had to refer to the 'help' card a significantly higher number of times than in the high analogy condition.

8.5 Discussion

The purpose of this last experiment was to 'fill in some of the blanks' left by the previous experiment. In attempting to achieve this the study has obtained mixed results. The primary aims of the experiment were

- To investigate the effect of a wider difference of analogy level on task performance

- To examine the connection between analogical visualisations and external cognition.
- To see if the errors made are systematically biased in any way by the representations

The findings with regard to these aims will now be expanded upon in more detail. However a few points will first be made on the methodology employed by this experiment

8.5.1 Methodology

In terms of methodology, this experiment was very similar to the last one, with the addition of a few seemingly minor enhancements, in order to provide a more complete picture of the cognitive processes involved. Chief among these was the replacement of the external 'help' card, with an on-screen version, the use of which could be precisely measured. While this produced useful additional information, part of the original rationale of the experiment was to try to replicate and extend some of the original findings in the previous experiment. The alteration of the information sources available to participants however has meant that the number of question answering strategies participants could use has also been reduced. One of the most easily adoptable strategies open to participants in the last study was to use both the help card and the question representations simultaneously. That was not possible this time. Ideally both questions and 'help' card would have been available on-screen at the same time, if subjects had desired it. The 15' monitor used in the study however was too small to allow the requisite level of detail in both information sources to be displayed. It was therefore felt that while comparability would be eroded, the constraining of the question answering strategies open to participants would still produce interesting and possibly more defined results. It should also be noted that based on the experience of subjects in the previous experiment, certain questions had been altered for this one in order to augment clarity and reduce unnecessary error rates. This iterative process of improvement however has given rise to a lack of comparability between this experiment and the last, while at the same time, fundamentally altering the profile of results.

8.5.2 Visual Analogy Level & Task Performance

One of the main findings in this experiment was that there is a significant main effect of analogy level. It could potentially be said therefore that analogy level determines how helpful representations are in tasks of this nature. This would also echo the findings from Experiment 1, in which the three representations (cylinder / wall / container) used in this and the previous experiment demonstrated a progressively stronger influence on how people assigned labels (e.g. 'Value', 'Availability', 'Package-Size') to the different pictorial aspects of the representation.

In terms of how analogy aids performance, it can be seen that the more complex the task, the more helpful the high analogy representation proves to be. There was therefore a smaller gap between tasks where only 1 variable considered and 2 or 3 needed to be considered. In the low 'analogy' condition, a greater gap could be seen between simple and more complex tasks where a greater memory load is imposed. Presumably then, the facilitative effect of analogy becomes more important and useful the more variables there are to be considered. There were however no striking qualitative differences in the pattern of results suggesting that analogy helps by prompting users as to what the different elements mean within the representation.

A few notes of caution however should be borne in mind. Firstly the design in this experiment while similar, is not the same as that in the previous experiment. This therefore makes direct comparison difficult. In addition, the profiles of the results in this experiment, are also very different. This is likely to be through the fact that a qualitatively different strategy (using the question representations as aids to arrive at the answer) could be used in the previous experiment, but not in this one (a point which is discussed in greater detail in the next section). The two experiments together therefore provide an interesting and suggestive view of the effect of analogy level with regard to task performance, however more experimentation would be necessary before firm conclusions could be made.

8.5.3 Visual Analogy & Strategy

One of the key aims of this experiment was to investigate the influence of analogy level on the adoption of a strategy of external cognition.

The previous experiment showed that the answers were viewed for longer in the high analogy condition, and despite this lead to quicker (although not statistically significant) decision times overall. An interpretation of this is that the answer representations themselves were being used to mentally compute the correct answers in a way that the Low-analogy representations were not. It was noted that the help card played a significant role in the last experiment, although it was unclear exactly what this was, and so in this experiment, the card was incorporated into the experimental program. The manner in which this was carried out however, forced a change of strategy from that used in the last experiment. This is because the help card could not be viewed simultaneously with the questions or answers.

In the previous experiment, more time was spent on the answer screen in the high analogy condition than in the Low-analogy condition, while this pattern was reversed on the question screen. In this experiment, this difference between conditions no longer existed. In both high analogy and Low-analogy conditions, more time was spent on the answer screen. This is superficially the same strategy that was adopted in the high analogy condition in the previous experiment, however the fact that the 'help' card could no longer be viewed at the same time as the question representations means that the meanings had to be internalised – a strategy which was not forced in the last experiment.

The 'Question' screen (which showed the question or key only) seems to have become relatively useless here, as the key could not be viewed simultaneously, and hence it appears to have been quickly passed by. One possibility is that this experiment did not support a strategy of internally constructing the answer while looking at the question and at the key simultaneously. This strategy appears to have been the strategy of choice before, when working with less helpful representations. As it could not be adopted here, participants in both analogy conditions were forced to act the same way.

It was appreciated before the experiment that the incorporation of the 'help' screen into the program would constrain the strategies available to participants. However it was only possible to appreciate with hindsight how exactly this would impact on the results. An investigation of external cognition was one of the key drivers of this experiment, and as such the constraining of the strategies available to participants could be described as having 'thrown the baby out with the bath water' – in as much as the external cognition strategy itself has been curtailed. This is an interesting demonstration of the importance (and fragility) of task strategy (Vessey, 1994). The experiment could usefully be repeated, allowing participants greater choice in the strategy they are allowed to adopt.

8.5.4 Error Systematicity

An issue which unfortunately could not be resolved in this experiment, was whether errors were made in a systematic pattern determined by the connotations in the metaphors. This is due in part to an insufficient appreciation of the variety of potential factors to which error could be attributed, as well as how cause and effect could be satisfactorily isolated. In addition, there were simply relatively few errors made. The ability to determine which button had been pressed did however allow one type of systematic pattern to be discovered – namely a significant trend towards choosing the centre option when making errors. One interpretation of this trend is that the centre option was seen as a default, or that the middle representation was somehow perceptually dominant. This trend says little about visual representations, but perhaps has implications for the future design of experimental interfaces, or indeed other types of computer interface, where such a visual arrangement might be involved.

8.5.5 Summary

To summarise, the results of this experiment have arisen only partially in the pattern expected. The key question of the effect of analogy level on effectiveness for a task of this type has been confirmed. The analysis of strategy adopted on the other hand has proved to be completely different to that expected. Instead of revealing that a higher level of visual analogy leads to a greater shift to external cognition therefore, the results have revealed that strategy adapts to reduce effort given the resources available. In future it would be advisable to allow the 'key' to be used simultaneously with the questions and representations, and monitor this systematically at the same time. Subjective measurements could also ideally be collected in order to make strategy adoption a central focus. Such measures would make an already analytically complicated experiment even more complicated, however the benefits of obtaining such data and the knowledge accrued from the process, would most likely make this worthwhile.

This study forms the final practical investigation of the thesis. The next chapter will now collect the most relevant findings from this and the other investigations and discuss them in the context of information visualisation as a whole from both a practical and theoretical perspective.

Chapter 9 - DISCUSSION

The results of each experiment have been discussed at the end of each relevant chapter. This section will now summarise these findings and describe how they complement existing literature in the area. A summary of how information visualisation can be informed by the results of the experiments will then be provided.

9.1 Results Summary

The results of the experiments have revealed the following:

In ***Experiment 1*** a continuum of visual analogy was proposed for the share price concept featured. A practical manifestation of this is that at the lower end of this continuum, allocation of iconic element to concept element is unconstrained – any visual aspect can be equally interpreted as meaning any part of the concept. At the upper end of this continuum the constraining of mapping between the visual and the conceptual is much stronger. At the highest end the representation is extremely specific, and at the lower end it is more abstract.

In ***Experiments 2&3*** it was demonstrated that in order to map the appearance of a particular iconic element to the meaning of the concept, a translation process is involved which involves a cognitive cost. In terms of the type of translations necessary, when using multidimensional icons, the need to translate from appearance to a verbal description of the concept is over and above that required to translate from appearance to verbal description of this appearance.

In ***Experiment 4*** it was shown that Multidimensional icons can produce performance which is comparable to that of tables and superior to that of bar graphs in tasks where a readout of certain discrete levelled values is required. This is despite the fact that a translation process is required to read the multidimensional icons. This suggests that the translation cost is not a barrier to the use of such representations, and indeed can yield improved performance over representations where (such as in the graph) the values can be read directly. It was also shown that users of such representations are not able to recognise how effective they are likely to be for such a task beforehand, although this becomes apparent after use.

In ***Experiments 5&,6*** it was demonstrated that the properties of analogical representations, namely that they can reflect the nature of and the relationship between variables in a given data set, can be of use where these variables require identification and subsequent cognitive inferences. This value increases, the more complex the subsequent inferences to perform. High analogy representations are able to perform this function more effectively than low analogy representations. A higher level of visual analogy also appears to lead to a qualitatively different task strategy being adopted, where possible, which makes greater use of the external representations themselves to keep track of a task problem as it is being answered. The strategy of using the external representations as a means to work out the answer also seems to be a strategy which takes time to learn effectively, but which delivers performance benefits when mastered.

These results fill out our understanding of the role of multidimensional icons in a number of ways. Firstly they have demonstrated a practical way of defining analogy level in terms of how consistently people map elements of an iconic representation to elements of an underlying concept. Secondly, they have shown that when being used (in this case in the context of a categorisation task) a mapping process is involved to anchor meaning to the visualisation. This goes above and beyond that required to simply describe what is shown by the icon (e.g. gold balls). Thirdly, it has been demonstrated that the help that visual analogy provides in helping people to identify different variables is such that multidimensional icons can outperform traditional ways of displaying the same data, even when these representations explicitly display the information. The fact that such analogical representations can be so helpful is not intuitively clear to users until they have gained experience with the representations, after which it becomes apparent. Fourthly, it can be seen that increasing the level of analogy increases the ease with which relevant aspects of such representations can be accessed for use in a given task at hand. In addition the incorporation of greater levels of analogy can also lead to the adoption of a fundamentally different task strategy by users. This being so despite the fact that the representations causing different task strategies can look very similar. The strategy, which a higher level of analogy appears to promote, relies on increased use of external physical representations. This strategy appears to have the potential to be more effective once sufficient experience has been gained. The most important effects will now be discussed along with the implication they have for choosing the design of multidimensional icons.

9.2 Visual Analogy & Multidimensional Icons

The focus of the experimental work has been multidimensional icons. One of the key questions around which this investigation has been based is the question of how to inform the design of such representations.

Spence & Parr (1991) raised the importance of iconic appearance as a way of deciding which type of icon to use. For displaying housing information therefore, a house can form a suitable basis, within which number of bedrooms can be mapped to number of bedrooms, distance from the station mapped to a clock on the outside wall, price by colour, etc. Spence (2001) puts the argument forward that a house is more suitable for showing housing information than a face for example, due to the fact that a house has a semantic relationship with the task, that would not be shared by a face or other object. This fact is of limited use however in the context of informing design for a number of reasons:

Firstly, there are not always clear iconic associations that can be used in making an icon choice. For example, it is difficult to come up with an appropriate icon when using share information. Secondly, there is little guidance purely on the basis of iconicity as to why to map price to colour, or time to a clock on the wall. The fact that such mappings seem intuitive or good default options is not of use when operating in areas where such intuitive icons and mappings do not exist. For this reason the more extensive description of visual analogy (Gattis, 2001) has been employed in this thesis, as a means of deciding upon 'more' and 'less' suitable designs..

Gattis's (2001) description deals not only with iconicity but also with polarity, associations and structural similarity. These additional concepts provide more support when dealing with abstract formless data, as they do not presuppose a physical object on which the representation can be based. The type of support that each of these individual concepts can provide will now be described in more detail.

Iconicity, as described by Gattis (2001) is largely the same as the principle used by Spence & Parr (1991) – namely it presupposes a real world physical object which can be used as a basis for representation. As the concept used in this thesis did not have an amenable iconic counterpart, strictly speaking, no comment on the use of iconicity can be made.

Association is a slightly more intangible concept, but one which is of importance to informing the design of representation choice. In the experiments described in this thesis, the representation at the low end of the analogy scale possessed few associations with regard to the underlying share concept with the exception of direction of mapping. In contrast, the high analogy representation contained many, including bronze, silver and gold metal types, and their link to an increasing hierarchy of value in the concept. Individual balls also contained some association with the concept of individual packages in the share concept. The glass as a container of the shares, defining the boundary of what they are applicable to, was also explicitly present in the high analogy representation and not present in the low (or medium) analogy representations. The more associations which are present in a given representation is therefore an important determiner of how supportive a particular representation can be in a task where values within the representation have to be identified and remembered for a short time while a mental computation or inference is carried out. An important fact also to bear in mind, is the strength of the individual associations. This is almost certain to have a bearing on how intuitive a particular visual analogy is. The theory is unable however to expand on this, not least given the fact that these are likely to vary from individual to individual.

Associations also refer to the common encountered mappings of real life, which also appear in language. Large Package size should therefore be represented by a large ball and not by a small ball. If directionality is violated then the consequences can be severe as has been demonstrated.

Linked to the concept of associations is also that of structural similarity. Structural similarity concerns the mapping of relations to relations and elements to elements, and higher order relations to higher order relations. This is inextricably linked with the concept of associations. In the high analogy representation used here therefore, Packages (an element) were mapped to balls (elements), while availability (the proportion of total packages available) a relation, was mapped to the proportion of the glass which was filled (relation). Structural similarity would therefore have been violated in terms of higher order relationship coherence if availability was mapped to packages and packages to the proportion of the glass filled. This would have meant that availability would be shown by the size of the balls and package size by the proportion of the glass filled. The incongruent mapping was not a mapping chosen by participants –although it could have been- indicating that it was unintuitive in the context of the share price concept used here.

An alternative way in which structural similarity could be violated would be if the levels of concept (i.e. high, medium, low) were mapped to the representation variables (e.g. height, metal & ball-size). In this case 'Availability' for example would always be shown by 'large' or 'high', 'Package Size' by 'medium', and 'Value' by 'small' or 'low'. This would necessitate 'Low' being mapped to 'Ball size' for example, 'Medium' being mapped to 'metal type, and 'High' to 'Height '. This would lead to the situation for example where:

Low Value = Small Ball Size
Medium Value = Bronze
High Value = Low height

This seems completely counterintuitive and needless to say was not chosen by participants.

The results of the thesis have therefore demonstrated that the theory of visual analogy can be practically instantiated and used as a basis upon which individual icons and the way they are mapped can be judged as suitable or unsuitable.

9.3 Visual Analogy & Mapping

In addition to providing information which can be used to make a judgement on icon design, the experiments in the thesis have also attempted to shed some light on the question of the processes involved in using such icons,.

It was clear from the experiments that there is a process involved above and beyond that required to merely describe what is in the icon. Categorising representations in terms of their meaning therefore takes considerably longer than doing so in terms of how they appear.

This may or may not be relevant to the task at hand. Many tasks can be carried out without a need to think in terms of meaning. Chernoff's faces provide such an example, where users only need to recognise facial expressions instead of thinking in terms of what the various aspects of the face mean (Moriarty, 1979). In such cases the extra time involved to think in terms of meaning, is not so relevant. In the experiments in this thesis however, the tasks did not concern the gaining of a broad impression, but rather the examination of individual variables and what they meant. It may have been that this process is relatively effortless, taking no longer than the time taken to understand that the card shows a "silver ball". It was demonstrated however that this is not the case. It is not possible at this stage to define exactly what the processes are behind this additional time. It may be that the appearance is translated into a description and then into a concept, or that the icon is seen and translated directly into a concept. It is not possible to say from the experiments here. More testing would be needed.

Despite the need to undertake this effortful process of attaching meaning to appearance, the use of 'high analogy' icons still appeared to lead to performance benefits over other representations commonly used for displaying such information namely the bar graph. It was proposed that a possible reason for this advantage of graphs was due to the fact that the identity and level of a particular variable are often able to be co-located in one position, in a way diagrams also allow. This is not something which is always possible when using graphs, and is a possible argument for the wider adoption of well chosen multidimensional icons. Although it was not tested here, it would have been interesting to see if the other icons also lead to a similar performance benefit. If not this would have provided further support for the benefit of incorporating high levels of analogy as a way of allowing concepts to be identified.

Turning now to the question of within-analogy performance. The experiments produced a number of findings which are interesting if not completely straight forward. In the experiment which compared the high (balls inside a glass) and medium (balls next to a glass wall) analogy representations, no outright significant difference in task time or accuracy could be seen. However the high analogy representation appeared to lead to a different task strategy being adopted where the question representations themselves (which were displayed in a multiple choice fashion) were used to arrive at the answer. When using the medium analogy representations on the other hand, participants appeared to use these answer representations less. It is proposed that when using the 'high analogy' representations, the answer was constructed in a step by step fashion involving a constant re-referring to these question representations and eliminating ones that did not fit. In the 'medium analogy' condition on the other hand, it appears that the question representations were used as little as possible, with the answer being constructed internally, and the question representations just being used once to compare if one of them was identical to the internal answer constructed. Arguably, it was easier to re-refer to the 'high' analogy representations as it was clearer to understand what signified what. In the 'low' analogy condition, it appears that this understanding was not so well supported and that the preferred strategy was to build the correct answer from scratch, rather than eliminate the multiple-choice candidates step by step. In terms of learning, it appears that the process of re-referring takes longer to perfect, but that it slowly leads to a faster performance level than when the answer is constructed internally.

A subsequent experiment was then designed to explore these findings in greater detail by increasing the analogy distance of the representations used in the two conditions by replacing the 'medium' with the 'low' analogy representations. This time no difference in strategy was evident. Both 'low' and 'high' analogy representations lead to the answers being constructed internally. As the high analogy condition had been present in both experiments, it initially seemed surprising that the task strategy had changed. However on closer inspection it became evident that a slight alteration (computerising the 'help' card, meaning it could no longer be viewed simultaneously with the question) had meant that the re-referring strategy was no longer preferred, presumably because it required a greater cognitive effort to remember the help information and then re-refer to the question representations.

In this situation where the strategy difference was eliminated, a significant difference in task completion time could however be seen. The high analogy representations could therefore be used more quickly. It can be presumed that this is for the same underlying reason as before, namely that it is easier to identify variables. Ideally then this ease is expressed through a strategy of external cognition. However when this is no longer efficient or is too much effort, analogy still provides support in allowing an internal answer to be constructed.

To summarise these rather complicated findings, it can be argued that a higher level of visual analogy makes it more obvious what the visual aspects of multidimensional icons are supposed to mean. This can lead to an easy task strategy being adopted, where a 'help' card is present, that spells out these mappings. Where such a help card is not present, higher levels of visual analogy allow internal representations of this information to be constructed more quickly. This leads to quicker completion times. Heeding the theory of visual analogy can therefore lead to better task performance when using such icons, although 'better' can mean less effort as well as quicker performance. It should be remembered however that the strategy of less effort, appeared to be becoming ever more quick, something that was not the case in the high effort strategy.

9.4 Design Implications

One of the main purposes of the work described in this thesis, was to produce findings which could inform the design of multidimensional icons. Taken as a whole, the experiments have been able to produce a number of clues as to aspects which need to be accounted for:

9.4.1 Visual Analogy

The key finding here is that visual analogy is important, and that it should be heeded. *Gattis's theory of visual analogy consists of a number of different* strands, which combine together and which when considered in isolation may be more or less important. Iconicity although not tested specifically here, is likely to be an important aspect to try and incorporate. Spence (2001) argues for the utility of this, and where it does not interfere with the other aspects of visual analogy, and where it is possible, it can only be recommended that representations are found which are in some sense iconic to the concept being represented. Similarly it can only be recommended that icons containing as many associations as possible are used provided that these are organised in a manner which is in accordance with structural similarity – namely that concept objects are mapped to visual objects and concept relations are mapped to visual relations. Ideally these should be structured in such a way that there is then a higher and structured organisation which relates the various elements to each other. In the case of the representations used, this means 'a glass'. Such a higher level concept then provides a framework for the fact that the glass has contents which can have separate and different properties. The relationship between the glass and its contents do not then have to be learnt afresh but can rely on prior knowledge of the user.

The results here also suggest that no matter how apt the iconicity or structural similarity that are used in a multidimensional icon, if the directionality is not congruent with that which users are likely to expect, then the icons will be extremely hard to use. This means that the relationships common in spoken language need to be heeded and that up or large should equate to more while down or small should equate to less.

In sum, heeding the different aspects of visual analogy is likely to be a useful way of designing appropriate multidimensional icons.

9.4.2 Education

In one of the studies it became clear that while multidimensional icons were able to show definite benefits in the tasks featured, this fact was not intuitively obvious to potential users. People, it seems, initially prefer graphical representation styles with which they have been educated and with which they have prior experience. Only after multidimensional icons have been used, are people able to recognise the benefits that they can provide. This may well have repercussions for the uptake of such applications. It would seem necessary therefore that a process of 'education' should take place to convince sceptical potential users that there are tangible benefits to be gained.

9.4.3 Mapping Many Dimensions

Some icon designs are more amenable to having many dimensions mapped to them than others. In a simple representation such as a cylinder , the number of obvious aspects against which concept variables can be mapped is much lower than in a more complex representation , which may have many details on which information can be mapped. Using a cylinder therefore, diameter, height and colour can be easily mapped, but there are not many more clear perceptual dimensions against which data can be mapped. It is possible to use other perceptual dimensions such as texture for example, but then the risk arises that this may lead to confusion – with the texture of the cylinder impacting on the colour. In the experiments here then, some colours appeared shinier than others, leading to the presumption that shininess itself was a variable. Where possible then the dimensions should be as clearly distinguishable as possible, and icons should be chosen to allow this, wherever possible.

9.4.4 Emergent Features

Connected to the previous point is the fact that some icons are more likely to give rise to emergent features than others. Emergent features are additional often unplanned features, which arise from the combined effect of several simple variables. Volume for example is one emergent feature that arose in the cylinder representation, this being the combined effect of manipulating the diameter and height. Some participants therefore thought that volume was a variable against which values would be mapped, when this was not intended to be the case.

Emergent features can therefore confound certain carefully chosen mappings, however at the same time they can also be used to map onto particularly salient conceptual variables. Where this arises from a combined effect of two simple variables, such as in the case described, then this can be seen as an ideal combination. Ideally as they are hard to avoid, they should be utilised wherever possible.

9.4.5 Making Perceptual Judgements

While visual analogy is an important aspect of any multidimensional icon, an important factor which needs to be taken into account is how well the levels of the different iconic elements (e.g. colour, height, shininess etc) can be judged. Height for example is likely to be relatively easy to judge over a range of different levels. Shininess on the other hand is likely to be less easy to judge over the same number of levels. This is important to consider as while a particular multidimensional icon may perfectly reflect the structure of the concept it is representing, if judgements cannot be easily made of the levels of the various elements, then the use of the icon is limited. Indeed, multidimensional icons in general are likely to be of limited use in tasks where precise readings are essential. If more precise readings are required then it makes sense to use another type of representation.

9.4.6 Suppressing Alternate meanings

The use of multidimensional icons which have real world connotations may also lead to the situation on occasion where the property of the object represented interferes with the understanding of the concept that is being represented.

In the case of the representations used here, value could be attributed to a combined scale, with small bronze balls at the low value end, and large gold balls at the high value end. In this case large silver balls may be perceived as being worth more than small gold balls which could potentially be the case in the real world. A process of education is therefore important before such visual analogical representations can be used, to ensure that the intended meaning is understood, and that an unintended but equally valid meaning is not assumed.

9.4.7 External Cognition

In the last two experiments described, it was apparent that the level of analogy leads to the adoption of different task strategies. The more successful appeared to be when heavy use was made of external aids (namely the help card) to answer the questions. When easy access to the help card was taken away, this strategy could not be adopted anymore. It therefore makes sense to allow users access to whatever external aids may be desirable. A further possibility related to this, which was not tested for specifically in this thesis is to allow such representations to support cognitive traces (i.e. mark, update and highlight information) as Scaife & Rogers (1997) suggest. Any such modification which supports the user to achieve the task in hand should be considered.

9.5 Shortcomings

The conclusions and generalisations being made here are the results of a process of scientific induction from the limited confines of the experiments described. This is both a normal and necessary step in the scientific acquisition of knowledge, however it gives rise to a number of issues, which must be mentioned along with the conclusions. These relate particularly to the information being represented, the representations, the users or participants and the organisation of the thesis itself, and will now be dealt with in turn.

Of key importance perhaps is the question of the tasks, the representations used and the applicability of the findings here outside of these limited domains. Both task and the data being represented were kept purposefully simple. This has been the same in all experiments– namely the concept of shares and share prices, varying in a limited amount of ways. The fact that there were only three variables and three levels by which they varied was sufficient here to demonstrate the effects of analogy level, however it is unlikely that there would be many situations in the real world where such a limited set of information would need to be represented. More likely is that there would be more variables, some of which may be infinitely variable. This question of variability is an important one. Traditional representations such as graphs are well designed to allow infinitely variable data to be represented, making use of a clearly visible position of a line or point in a 2D space. This 2D space is also marked by a scale which allows amounts to be easily read. Multidimensional icons on the other hand, do not allow for such a scale to be easily incorporated. In addition, variations within the perceptual variables used such as volume and colour are not so easy to judge, especially in the absence of a scale against which to compare them. This fact is likely to be an important determiner of the value of a given multidimensional icon for any task.

It also has to be borne in mind that the tasks featured in the experiments here were somewhat artificial in the sense that they were simple and usually of a multiple choice variety. As Spence & Parr (1991) and Moriarty (1979) both point out, the true benefit of analogical representations is likely to be found in situations where many variables need to be judged at once, and where there is no clear-cut answer. Multidimensional icons are therefore unlikely to be an appropriate representation for many types of task, regardless of the amount of analogy they contain. The tasks here were chosen as they were an amenable way of investigating and demonstrating the effects of analogy in a controlled setting and not because the tasks themselves are striving to attain real world validity. The claim 'visual analogy leads to more suitable representations' is therefore task specific – the task being when an understanding of the meaning of the individual elements within the overall icon is of importance, and when these values can be easily accessed and read.

A further set of issues arises with regard to the actual representations themselves. First of all there was no formal process through which the representations were derived. As no such process exists this situation was unavoidable. To an extent this problem was dealt with by the first experiment which demonstrated that participants mapped particular concepts to particular perceptual features, however it is not possible to be sure that the analogy of the balls in the glass was the most appropriate representation possible. In as much as the experiments were concentrating on the intra-analogy variable of analogy level between representations which had already been 'measured' (by mapping choices in Experiment 1) this is not of crucial importance, however it would be ideal if there was a formal process of deriving visual analogies for a particular concept. Such a technique may for example use some form of discourse analysis, however this is yet to be devised.

It should also be emphasised that all the experiments carried out in the thesis used 'novice' participants. This meant that they were unschooled in financial share dealing and had no previous experience of the task they were asked to carry out. It has therefore been shown that visual analogy can be useful for this class of user, however it is impossible to make a comment on how expert users would view this type of representation for the task featured. It may be in this case that the useful aspect of analogy (primarily that it brings attention to the relationships within the data, which appears to have a mnemonic facilitation effect) is no longer that useful as these relationships are already clearly internalised. The conclusions stated here cannot therefore be described as universal.

The final key issue of the thesis is the overall organisation of the experiments themselves. This has been rather 'organic' to say the least, and with hindsight it is possible to see how a more logical format could have been adopted – for example combining Experiments 5 & 6 into a larger more comprehensive design where both directionality and help card usage could be examined with all three of the styles of representation used in the thesis. As it was Experiment 6 was designed based on the analysis of the findings and the shortcomings of Experiment 5. Hence direct comparability was traded off for design improvements.

Further considerations, which have not been mentioned so far, are those of personality type and culture. All participants in the experiment were from westernised culture, and it was therefore possible to be fairly sure that there would be a commonly understood meaning in relation to the container and balls representing shares and share prices. This may be a completely incomprehensible idea in other cultures however. The use of analogy is strongly culture dependant.

9.6 Further Research

The results of the experiments have revealed a number of areas which could benefit from further exploration:

Firstly, all the experiments described maintained the same mapping pattern, which was decided upon after the results of Experiment 1. This has meant that it has been possible to say reliably that the mappings chosen were the most congruent. A degree of manipulation was incorporated when the directionality was varied in Experiment 4 however this was the limit in this regard. The experiments could usefully be complemented with an additional set of experiments in which these mappings (i.e. value=metal type) were systematically varied to see if there are any differences in performance. Also of interest would be to change the concept used so that it was then best fitted to the cylinder and least fitted to the container. If the findings could be maintained, this would provide a more robust case for the use of visual analogy

As has been mentioned already, all of the experiments outlined here have been carried out using discrete variables. A repetition of the experiments using continuous variables would be interesting along with a repetition in which more than three variables were incorporated into the representations. The use of continuous variables would then open up an interesting question regarding how well this mix of perceptual variables would allow such data to be represented. The question of whether some percepts (e.g. volume) incorporate systematic perceptual bias could also usefully be investigated. Were this the case an understanding of how this could be usefully employed in a constructive manner would be very useful.

A further finding of the experiments was that strategy differs markedly according to the representations used. It would therefore be useful to investigate this issue more systematically, taking more extensive measures of exactly how and why such strategies differ. Such measures may extend to interviews and video-sessions of the different representations being used..

Finally, it should be remembered that Card, MacKinlay & Schneiderman (1999) define information visualisation as "The use of computer-supported, interactive, visual representations of data to amplify cognition". This thesis has not touched at all upon interaction, and the different methods and interface issues that this raises (Krohn, 1996; Coury et al., 1997). This is necessary to gain anything resembling a complete picture of the area.

9.7 Multidimensional Icons and Information Visualisation

The focus of the empirical work in this thesis has been on multidimensional icons. The design guidelines which have been stated here are therefore strictly speaking relevant only to multidimensional icons. The properties of multidimensional icons however, are nevertheless central to information visualisation as they aim to provide formless abstract data with a form. This form must inevitably be borrowed from somewhere else and can employ analogy with existing real world objects to a greater or lesser extent. Where this does not involve the use of representations with established conventions (such as bar graphs and scatterplots),it can be argued that any such representation falls at least to some extent under the banner of multidimensional icons. The position of this thesis therefore has been that a study of analogy in multidimensional icons is synonymous with an exploration of analogy in information visualisation as a whole.

9.8 Summary

In summary, the thesis has revealed a number of findings which deal with the mechanics of using analogical representations as well as providing a basis against which they can be more effectively designed.

In terms of using such representations, it has been shown that this incurs a cost which can be expressed in terms of time, as the meaning of the representation is worked. Nevertheless the process of dong this can be seen to show benefits against other more traditional forms of representing such information, where an identification and readout of a simple number of variables is involved. This is not recognised intuitively by users until after they have actually gained experience using such representations.

In terms of deriving findings which provide a more informed basis against which such representations can be designed - it has been shown that this basis lies in the concept of visual analogy, which can be viewed on a continuum from 'low' to 'high'. A practical manifestation of this continuum is that users are more specific about what a mapping can mean when a representation is at the 'high' end of the continuum than when it is at the 'low' end. This specificity can then be put to practical use within the context of multidimensional icons allowing the meaning of these icons to be understood more readily, and to allow easier task strategies to be followed.

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Chapter 11 - APPENDICES

Appendix 5-1

POVRAY Code To Render 'Glass'

G6l -(Gold Metal, Large Diameter, Low Height)

```
#include "Colors.inc"
#include "Shapes.inc"
#include "Textures.inc"

global_settings
{assumed_gamma 2.2
max_trace_level 5}

plane
{<0,1,-0.5>,-0.5
pigment {checker color Gray65, color NeonBlue} }

light_source {<10,20,-20> color White}
light_source {<-10,20,-20> color White}
 light_source {<0,20,20> color Gray50 shadowless}

camera
{location  <0, 3 ,-5>
look_at   <0, 1.8 ,-2>}


#declare High = texture {Gold_Metal
     finish {ambient 0.3}}


#declare y0=(2.75/3)*1-0.6
#declare y1=(2.75/3)*2-0.6
#declare y15=2
#declare y2=(2.75/3)*3-0.6

cylinder
{<0,0,0>,<0,2.75,0>,1.6
  open
   pigment { Grey filter 1.2 }
        finish
         {ambient 0.003
          diffuse 0.16
          reflection .15
          refraction 0.88
          ior 1.1
          specular 0.01
          roughness .003}}


//Bottom Row of spheres - centre strand            BOTTOM
sphere //front centre
{<0,y0,-1>,0.6
   texture { High }}

sphere //behind front centre
{<0,y0+0.04,-0.42>,0.6
   texture { High }}

sphere //behind front centre-1
{<0,y0+0.04,0.18>,0.6
   texture { High }}

sphere //behind front centre-2
{<0,y0+0.05,.78>,0.6
   texture { High }}

sphere //behind front centre-3
```

```
{<0,y0+0.04,.8>,0.6
   texture { High }}

//centre strand +1 right
sphere //1st
{<0.6,y0,-.7>,0.6
   texture { High }}

sphere //2nd
{<0.6,y0+0.04,-.1>,0.6
   texture { High }}

sphere //3rd
{<0.6,y0+0.04,.5>,0.6
   texture { High }}

sphere //4th
{<0.6,y0,1>,0.6
   texture { High }}

//centre strand +1 left
sphere //1st
{<-0.6,y0,-.7>,0.6
   texture { High }}

sphere //2nd
{<-0.6,y0+0.04,-.1>,0.6
   texture { High }}

sphere //3rd
{<-0.6,y0+0.04,.5>,0.6
   texture { High }}

sphere //4th
{<-0.6,y0,1>,0.6
   texture { High }}


//centre strand +2 right

sphere //1st
{<1,y0,-0.42>,0.6
   texture { High }}

sphere //2nd
{<1,y0+0.04,0.18>,0.6
   texture { High }}

sphere //3rd
{<1,y0+0.04,.78>,0.6
   texture { High }}

//centre strand +2 left

sphere //1st
{<-1,y0,-0.42>,0.6
   texture { High }}

sphere //2nd
{<-1,y0+0.04,0.18>,0.6
   texture { High }}

sphere //3rd
{<-1,y0+0.04,.78>,0.6
   texture { High }}
```

Appendix 5-2

POVRAY Code To Render 'Wall'

G6l -(Gold Metal, Large Diameter, Low Height)

```
#include "Colors.inc"
#include "Shapes.inc"
#include "Textures.inc"

global_settings
{assumed_gamma 2.2
max_trace_level 5}

plane
{<0,1,-0.5>,-0.5
pigment {checker color Gray65, color NeonBlue} )

light_source {<10,20,-20> color White}
light_source {<-10,20,-20> color White}
 light_source {<0,20,20> color Gray50 shadowless}

camera
{location  <0, 3 ,-5>
look_at   <0, 1.8 ,-2>}


#declare High = texture {Gold_Metal
     finish {ambient 0.3}}


#declare x0=(0.3)
#declare x1=(0.45)
#declare x2=(0.3)

#declare y0=(1.85/2)*1-0.6
#declare y1=(1.85/2)*2-0.6
#declare y2=(1.85/2)*3-0.6

#declare z0=(-0.7)
#declare z1=(-0.7)
#declare z2=(-0.7)



box
{<-2.05,2.75,-1.65>
 <-1.95,0,0.55>
pigment { Grey filter 1.05  }
        finish
        {ambient  0.003
         diffuse  0.16
         reflection  .15
         refraction  0.88
         ior  1.1
         specular  0.01
         roughness  .003}}


//Closest 6           BOTTOM
sphere //Leftest
{<x0-1.8,y0,z0-0.6>,0.6
   texture { High }}

sphere //2
{<x0-1.1,y0,z0-0.6>,0.6
   texture { High }}
```

```
sphere //3
{<x0-0.4,y0,z0-0.6>,0.6
   texture { High }}

sphere //4
{<x0+0.4,y0,z0-0.6>,0.6
   texture { High }}

sphere //5
{<x0+1.1,y0,z0-0.6>,0.6
   texture { High }}



//Middle 6
sphere //Leftest
{<x0-1.8,y0,z0>,0.6
   texture { High }}

sphere //2
{<x0-1.1,y0,z0>,0.6
   texture { High }}

sphere //3
{<x0-0.4,y0,z0>,0.6
   texture { High }}

sphere //4
{<x0+0.4,y0,z0>,0.6
   texture { High }}

sphere //5
{<x0+1.1,y0,z0>,0.6
   texture { High }}



//Back 6
sphere //Leftest
{<x0-1.8,y0,z0+0.6>,0.6
   texture { High }}

sphere //2
{<x0-1.1,y0,z0+0.6>,0.6
   texture { High }}

sphere //3
{<x0-0.4,y0,z0+0.6>,0.6
   texture { High }}

sphere //4
{<x0+0.4,y0,z0+0.6>,0.6
   texture { High }}

sphere //5
{<x0+1.1,y0,z0+0.6>,0.6
   texture { High }}
```

Appendix 5-3

POVRAY Code To Render 'Cylinder'

G6I – Bright Pink, Large Diameter, Low Height

```
#include "Colors.inc"
#include "Shapes.inc"
#include "Textures.inc"

global_settings
{assumed_gamma 2.2
max_trace_level 5}

plane
{<0,1,-0.5>,-0.5
pigment {checker color Gray65, color NeonBlue} }

light_source {<10,20,-20> color White shadowless}
light_source {<-10,20,-20> color White shadowless}

camera
{location  <0, 3 ,-5>
look_at   <0, 1.8 ,-2>}


//DECLARATIONS

#declare Glassic = texture {
pigment {Grey filter 1.2}
       finish
        {ambient 0.003
         reflection .1
         refraction 0.88
         ior 1.1
         specular 0.01
         roughness .003} }


#declare High =
texture
{pigment {NeonPink}
   finish {
   ambient 0.45
   diffuse 1
   reflection .4
   metallic}}
             texture {
pigment {Grey filter 1}

       finish
        {ambient 0.003
         diffuse 0.03
         reflection .0
         refraction 0.88
         ior 1.1
         specular 0.01
         roughness 0.1} }


#declare Med =
texture
{pigment {NeonPink}
   finish {
   ambient 0.3
   reflection .3
   }}
```

```
texture {
pigment {Grey filter .55}
normal { bumps 0.07 scale 0.02 }
       finish
        {ambient 0.00
         diffuse 0
         reflection .0
         refraction 0.88
         ior 1.1
         specular 0.01
         roughness .3} }


#declare Low =
texture
{pigment {NeonPink}
   finish {
   ambient 0.3
   reflection .3
   }}
texture {
pigment {Grey filter .18}
normal { bumps 0.08 scale 0.03 }

       finish
        {ambient 0.00
         diffuse 0.0
         reflection .0
         refraction 0.88
         ior 1.1
         specular 0.01
         roughness 1} }


//ADJUSTABLES :
 //Y-High=2.75, Medium=1.83 , Low= 0.92
//R-High=1.6 , Medium=0.85  , Low=0.3
#declare y1=0.92;
#declare r1=1.6;



//MEASURING STICK
cylinder
{<-1.6,0,0>,<-1.6,2.75,0>.023
texture {Glassic}}

sphere
{<-1.6,2.75,0>.05
texture {Glassic }}

cylinder
{<-1.6,0,0>,<1.6,0,0>.023
texture {Glassic}}

sphere
{<-1.6,0,0>.05
texture {Glassic }}

sphere
{<1.6,0,0>.05
texture {Glassic }}


//cylinder

cylinder
{<0,0,0>,<0,y1,0>r1
texture {High}
```

Appendix 5-4

Consent Form

I ______________________ give consent to take part in this experiment. I understand that my participation is purely voluntary and that I am free to leave at any time.

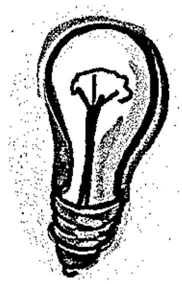
I certify that I possess normal colour vision and have no visual condition I am aware of that may influence the results of the experiment.

Signature: ______________________________

Date: ______________________

Appendix 5-5

Instructions – Experiment 1



Βαχκγρουνδ

You are helping with the design of a new information display system to show information about company stock market shares.

The system uses the image of a stack of balls next to a glass wall. The stack consists of balls which are either Gold, Silver or Bronze. These balls may be one of three sizes (large, medium or small) and stacked up to one of three heights (low, medium high). Each stack represents one company.

In this scenario there are three factors which need to be taken into account when looking at shares. These factors relate to how much the shares cost to buy, how many shares are available to be bought for a particular company and the size of the clusters in which the shares must be bought at one time, otherwise known as package size.

The three pieces of information which are therefore shown on the depictions are:

Value: The prices of company shares are constantly changing. The value shown indicates the relative value of a company's shares at that moment in time. This value has been calculated by the computer taking into account many different factors and is a judgement on whether the price of that company, in comparison to other similar companies is 'High', 'Low' or 'Medium'.

Availability: A large proportion of company shares are often owned privately and cannot be bought. Availability refers to the percentage of company shares which are actually available to be bought on the open market. The availability is either 'High', 'Low' or 'Medium'.

Package Size: This refers to the size of the groups in which the shares must be bought. The larger the package size, the more shares must be bought at once. The size of these packages is either 'High', 'Low' or 'Medium'.

Appendix 5-6

Questionnaire - Experiment 1, 3, 4

Questions

1. Company A's shares must be bought in groups of 50 while Company B's shares must be bought in groups of 100. Which company has the highest Package Size? (Please Circle)

   Company A
   Company B
   Equal

2. The chairman of Company X keeps 51% of shares in his company while company Y's chairman keeps 30% of his. The remaining shares are freely available. Which company has the highest availability?

   Company X
   Company Y
   Equal

3. The Oil Company Oxaco owns 10 oil fields in which huge reserves of oil have unexpectedly been discovered. After this news is released, is the value of the company's shares likely to be:

   High
   Medium
   Low

4. It is widely known that Company Q is having problems and is likely to declare Bankruptcy in the next few days. Is the value of the company's shares likely to be:

   High
   Medium
   Low

5. Company X's shares must be bought in groups of 50 while Company Y's shares must be bought in groups of 200. Which company has the highest Package Size?

   Company X
   Company Y
   Equal

6. The Board of Company A keeps 49% of shares in the company while Company B's board keeps only 10% of theirs. The remaining shares are freely available. Which company has the highest availability

   Company A
   Company B
   Equal

Appendix 5-7

POVRAY Metal Protocol

Original

Gold

```
#declare High = texture {
      pigment { BrightGold }
            finish
                  {ambient .036
                   diffuse .55
                   specular 1
                   roughness .001
                   reflection .75
                   metallic}}
```

Silver

```
#declare Med = texture {
      pigment { Silver }
            finish
                  {ambient .036
                   diffuse .55
                   specular 1
                   roughness .001
                   reflection .75
                   metallic}}
```

Bronze

```
#declare Low = texture {
      pigment { Bronze }
            finish
                  {ambient .036
                   diffuse .55
                   specular 1
                   roughness .001
                   reflection .75
                   metallic}}
```

Enhanced

Gold

```
#declare High = texture {Gold_Metal
     finish {ambient 0.3}}
```

Silver

```
#declare Med = texture {Gold_Metal
     finish {ambient 0.3}}
```

Bronze

```
#declare Low = texture {Gold_Metal
     finish {ambient 0.3}}
```

Appendix 6-1

Pre & Post Test Questionnaire – Experiment 2

Participant No.__________

The purpose of this questionnaire is to find out your opinions on a number of factors concerning the representations in front of you. Please place an 'x' along each scale below to indicate your opinion in each question.

1. How would you rate the different methods in terms of attractiveness?

Verbal

Very Unattractive |___|___|___|___|___|___|___| Very Attractive

Metaphor

Very Unattractive |___|___|___|___|___|___|___| Very Attractive

Graph

Very Unattractive |___|___|___|___|___|___|___| Very Attractive

2. How quickly do you think each method will let you perform the sorting task?

Verbal

Very Slowly |___|___|___|___|___|___|___| Very Quickly

Metaphor

Very Slowly |___|___|___|___|___|___|___| Very Quickly

Graph

Very Slowly |___|___|___|___|___|___|___| Very Quickly

3. How easy do you think it will be to make mistakes with each method?

Verbal

Very Difficult |___|___|___|___|___|___|___| Very Easy

Metaphor

Very Difficult |___|___|___|___|___|___|___| Very Easy

Graph

Very Difficult |___|___|___|___|___|___|___| Very Easy

4. How well do you think each method will allow you to focus on the information you need to know?

Verbal

Not well |___|___|___|___|___|___|___| Very Well

Metaphor

Not well |___|___|___|___|___|___|___| Very Well

Graph

Not well |___|___|___|___|___|___|___| Very Well

5. How unappealing do you find the appearance of each method ?

Verbal

Very Appealing |___|___|___|___|___|___|___| Very Unappealing

Metaphor

Very Appealing |___|___|___|___|___|___|___| Very Unappealing

Graph

Very Appealing |___|___|___|___|___|___|___| Very Unappealing

6. How much do you think each method would slow you down when doing the sorting task?

Verbal

Not at all |__|__|__|__|__|__|__| Very Much

Metaphor

Not at all |__|__|__|__|__|__|__| Very Much

Graph

Not at all |__|__|__|__|__|__|__| Very Much

7. How accurately do you think each method will let you perform the task?

Verbal

Very Inaccurately |__|__|__|__|__|__|__| Very Accurately

Metaphor

Very Inaccurately |__|__|__|__|__|__|__| Very Accurately

Graph

Very Inaccurately |__|__|__|__|__|__|__| Very Accurately

8. How easy do you think it will be to ignore information you don't need when sorting?

Verbal

Very Difficult |__|__|__|__|__|__|__| Very Easy

Metaphor

Very Difficult |__|__|__|__|__|__|__| Very Easy

Graph

Very Difficult |__|__|__|__|__|__|__| Very Easy

9. Please Rank the methods in terms of which you would most like to use, putting '1' for most and '3' for least.

Verbal ☐

Metaphor ☐

Graph ☐

10. Please add any comments you have on the task or on the representations

Please Turn Over

Sex:

Male ☐

Female ☐

Age:

18-20 ☐
21-25 ☐
26-30 ☐
31-40 ☐
41+ ☐

Occupation or degree:

____

Thank You Very Much For Taking Part

Appendix 6-2

HYPERCARD Button Script - Experiment 2

Right Answer

```
On mouseUp
      RightRandom
End mouseUp
```

Wrong Answer

```
On mouseUp
      Global mcbox
      Put the short name of me into mcbox
      WrongRandom
End mouseUp
```

Appendix 6-3

HYPERCARD Card Script - Experiment 2

```
On opencard

      --hideous
      global I
      put "B6m.pict" into I
      picture I, file, rect, false, 8
      set the loc of window I to "30, 150"

end opencard
```

Appendix 6-4

Hypercard Training Stack Script – Experiment 2

```
on openStack
  global i, cardNo, count
  hide menuBar
  put empty into i
  put empty into count
  put empty into mcbox
  put empty into bkbox
  put empty into mcboxv
  put empty into bkboxv
  put empty into mcboxa
  put empty into bkboxa
  put empty into cd field "array" of card "Results"
  randomise
end openStack

-- create a random presentation list
on randomise
  put empty into randomlist
  put the itemDelimiter into delim
  repeat until the number of items in randomlist is 10
    get random of 27
    if (delim&it&delim) is not in (delim&randomList) then
      put it & delim after randomList
      put 33-it & return after cd field "array" of card "Results"
    end if
  end repeat
  delete last char of randomList
end randomise

--Start Card advance to random
on startRandom
  global cardNo
  global count
  put line 1 of cd field "array" of card "Results" into CardNo
  delete line 1 of cd field "array" of card "Results"
  add 1 to count
  go card cardNo
  put count into cd field "countbox"
end StartRandom


-- Advance to a random card
on nextRandom
  global cardNo
  global count
  get random of 27
  put 34-it & return after cd field "array" of card "Results"
  put line 1 of cd field "array" of card "Results" into CardNo
  delete line 1 of cd field "array" of card "Results"
  add 1 to count
  go card cardNo
  put count into cd field "countbox"
```

```
end nextrandom


-- RIGHT ANSWER
on rightRandom
  global i
  global cardNo
  global count
  global mcbox
  put empty into cd field "countbox"
  if line 1 of cd field "array" of card "Results" is empty then
    put "rescard" into CardNo
  else
    put line 1 of cd field "array" of card "Results" into CardNo
    delete line 1 of cd field "array" of card "Results"
    add 1 to count
  end if
  put the short name of this card & return after cd field "data" of
card "results"
  close window i
  put empty into cd field "countbox"
  go card cardNo
  put count into cd field "countbox"
end rightRandom


-- WRONG ANSWER
on wrongRandom
  global bkbox
  global bkboxv
  global bkboxa
  global mcbox
  global mcboxv
  global mcboxa
  put the short name of this card into bkbox
  put the charToNum of first char of bkbox into bkboxv
  put the charToNum of first char of mcbox into mcboxv
  put the charToNum of last char of bkbox into bkboxa
  put the charToNum of last char of mcbox into mcboxa
  put the name of this card && mcbox & return after cd field "data" of
card "results"
  put empty into cd field "countbox"
  if bkboxv=mcboxv then go cd "AvExpl"
  if bkboxa=mcboxa then go cd "VaExpl"
  if bkboxv≠mcboxv and bkboxa≠mcboxa then go cd "VaAvExpl"
end wrongRandom


//CLOSE window i, e1, e2
on x
  global i
  close window i
end x

on e
  global e1, e2
```

```
  close window e1
  close window e2
end e


on openCard
  global result
  startRecord
end openCard

on closeCard
  endRecord
end closeCard


-- record the moment the current card is opened
on startRecord
  global startTime
  put the ticks into startTime
end startRecord

on endRecord
  global result
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put the name of this card & tab & tab && elapsedTime & return after
cd field "RecordTime" of card "Results"
end endRecord

-- SHOW WINDOWS & ADD TIME
on w
  global i
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put "REV " & the name of this card & tab & tab && elapsedTime &
return after cd field "RecordTime" of card "Results"
  show window i

end w

on clear
  global result, count
  put emptu into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Intro1"
  put empty into cd field "resbox" of card "rescard"
  put empty into count
  put empty into cd field "array" of card "Results"
end clear


-- SAVE DATA -------------------------------------------------

on saveData
```

```
global Data2

-- putting the name, time and date into the desktop File name?

put cd field "subjectId" of card "Intro1" into File2
put "-Con1-" && the date after File2
open file File2

-- putting the name, time and accuracy into the saved results File?

put "EXPERIMENT 5: Metaphor - Condition 1" && return into Data2
put the date && the time && return after Data2


put cd field "subjectId" of card "Intro1" after Data2
put return & return & cd field "Data" of card "Results" after Data2
put return & cd field "RecordTime" of card "Results" after Data2

write Data2 to file File2



--clear the data recording fields for next subject

put empty into result
put empty into cd field "Data" of card "Results"
put empty into cd field "RecordTime" of card "Results"
put empty into cd field "subjectId" of card "Intro1"

end saveData
```

Appendix 6-5

HYPERCARD Stack Script – Experiment 2

```
on openStack
  global i, result, cardNo, count
  hide menuBar
  put empty into result
  put empty into i
  put empty into count
  put empty into mcbox
  put empty into cd field "array" of card "Results"
  put empty into cd field "resbox" of card "rescard"
  randomise
end openStack

-- create a random presentation list
on randomise
  put empty into randomlist
  put the itemDelimiter into delim
  repeat until the number of items in randomlist is 27
    get random of 27
    if (delim&it&delim) is not in (delim&randomList) then
      put it & delim after randomList
      put 29-it & return after cd field "array" of card "Results"
    end if
  end repeat
  delete last char of randomList
end randomise

-- Advance to a random card
on nextRandom
  global cardNo
  global count
  put empty into cd field "countbox"
  put line 1 of cd field "array" of card "Results" into CardNo
  delete line 1 of cd field "array" of card "Results"
  add 1 to count
  go card cardNo
  put count into cd field "countbox"
end nextrandom


-- RIGHT ANSWER
on rightRandom
  global i
  global result
  global cardNo
  global count
  global mcbox
  put empty into cd field "countbox"
  if line 1 of cd field "array" of card "Results" is empty then
    put "29" into CardNo
  else
    put line 1 of cd field "array" of card "Results" into CardNo
    delete line 1 of cd field "array" of card "Results"
```

```
    add 1 to count
  end if
  put the short name of this card & return after cd field "data" of
card "results"
  close window i

  add 1 to result
  go card cardNo
  put count into cd field "countbox"
end rightRandom



-- WRONG ANSWER
on wrongRandom
  global i
  global cardNo
  global count
  global mcbox
  put empty into cd field "countbox"
  if line 1 of cd field "array" of card "Results" is empty then
    put "29" into CardNo
  else
    put line 1 of cd field "array" of card "Results" into CardNo
    delete line 1 of cd field "array" of card "Results"
    add 1 to count
  end if
  put the name of this card && mcbox & return after cd field "data" of
card "results"
  close window i

  go card cardNo
  put count into cd field "countbox"
end wrongRandom



//CLOSE window i, e1, e2
on x
  global i
  close window i
end x

on e
  global e1, e2
  close window e1
  close window e2
end e


on openCard
  global result
  startRecord
end openCard

on closeCard
  endRecord
```

```
end closeCard

-- record the moment the current card is opened
on startRecord
  global startTime
  put the ticks into startTime
end startRecord

on endRecord
  global result
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put the name of this card & tab & tab && elapsedTime & return after
cd field "RecordTime" of card "Results"
end endRecord

-- SHOW WINDOWS & ADD TIME
on w
  global i
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put "REV " & the name of this card & tab & tab && elapsedTime &
return after cd field "RecordTime" of card "Results"
  show window i

end w

on clear
  global result, count
  put emptu into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Intro1"
  put empty into cd field "resbox" of card "rescard"
  put empty into count
  put empty into cd field "array" of card "Results"
end clear


-- SAVE DATA --------------------------------------------------

on saveData
  global Data2


  -- putting the name, time and date into the desktop File name?

  put cd field "subjectId" of card "Intro1" into File2
  put "-Con1-" && the date after File2
  open file File2


  -- putting the name, time and accuracy into the saved results File?
```

```
  put "EXPERIMENT 5: Metaphor - Condition 1" && return into Data2
  put the date && the time && return after Data2


  put cd field "subjectId" of card "Intro1" after Data2
  put return & return & cd field "Data" of card "Results" after Data2
  put return & cd field "RecordTime" of card "Results" after Data2

  write Data2 to file File2



  --clear the data recording fields for next subject

  put empty into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Intro1"
  put empty into cd field "resbox" of card "rescard"


end saveData
```

Appendix 6-6

Instructions – Experiment 2

Your Name :

Welcome to The Training Exercise

This purpose of this program is to evaluate your potential as a 'Share Scout'.

The job of a Share Scout is to rapidly be able to sort companies according to their different attributes.

The next few pages will explain what these attributes are and how they are shown.
Before you go on though, could you please make sure your name is typed in, in the box in the top right hand corner......

When you've done this, press the 'OK' button to continue:

OK

In this scenario, each company has two attributes. These are VALUE and AVAILABILITY:

VALUE

VALUE refers to how much a company is worth. A company which is about to go Bankrupt for example, will have a low Value. On the other hand, a company which is seen as doing well will have a high Value.

AVAILABILITY

Companies will have differing amounts of shares available on the open market at different times. When lots of people want to sell their shares in a particular company then there will be lots of shares available, and the company will have a high Availability. If on the other hand, lots of people are holding on to their shares in a particular company and don't want to sell then the company will have a 'low availability'.

BACK

OK

What Do The Computer Visualisations Show?

The way in which VALUE and AVAILABILITY are shown by the computer will now be decribed (They will be shown on the next page):-

Each company is represented by a glass. The glass (or company) contains balls which represent groups of shares. The company can be thought of as a container for the shares much as a glass could be a container for balls in real life.

The balls themselves represent the shares and can be seen to be more or less valuable according to what metal they are made of whether it is Gold as most valuable, Silver for medium value or Bronze as least valuable.

As the company is represented by the framework of the glass, and the shares which make up the company are the balls in the glass, the amount of shares available is shown by how full of balls the glass is. If there are only a small amount of shares available to you, then only a few balls will be visible, and if the maximum amount is available then the glass will appear full of balls all of which are available to you.

To recap then: There are two ways in which companies differ that are important to you - VALUE & AVAILABILITY. These are shown by METAL TYPE & LEVEL OF BALLS IN THE GLASS. Each of the these variables will be either low, medium or High.

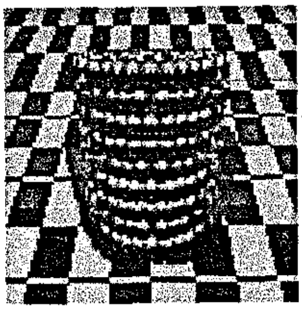
This will now be demonstrated on the next Page.........

BACK

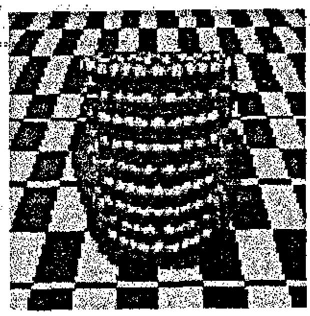
OK

VALUE

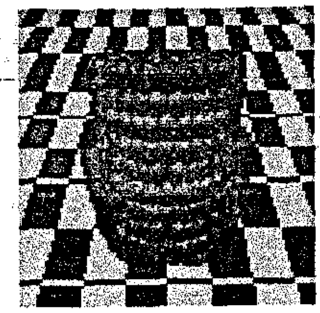
Value is shown by the type of metal which the balls are made of: Gold, Silver or Bronze.



High



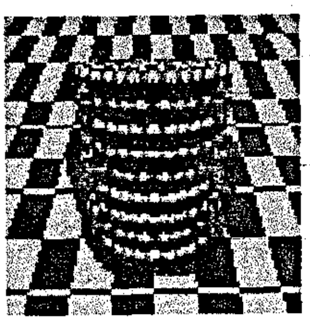
Medium



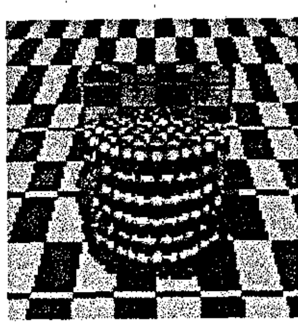
Low

AVAILABILITY

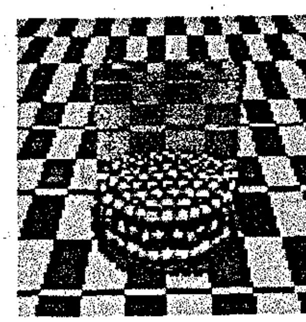
Availability is shown by the height of the balls in the glass.



High



Medium



Low

The Balls also differ in size in some cases. This is not important.

BACK

OK

There will now follow a practice session in which it can be seen how the companies should be sorted. If you answer any of the questions incorrectly the computer will explain how the correct answer should be arrived at. Once you have answered 10 questions correctly the practice session will end and you will be able to start the proper test.

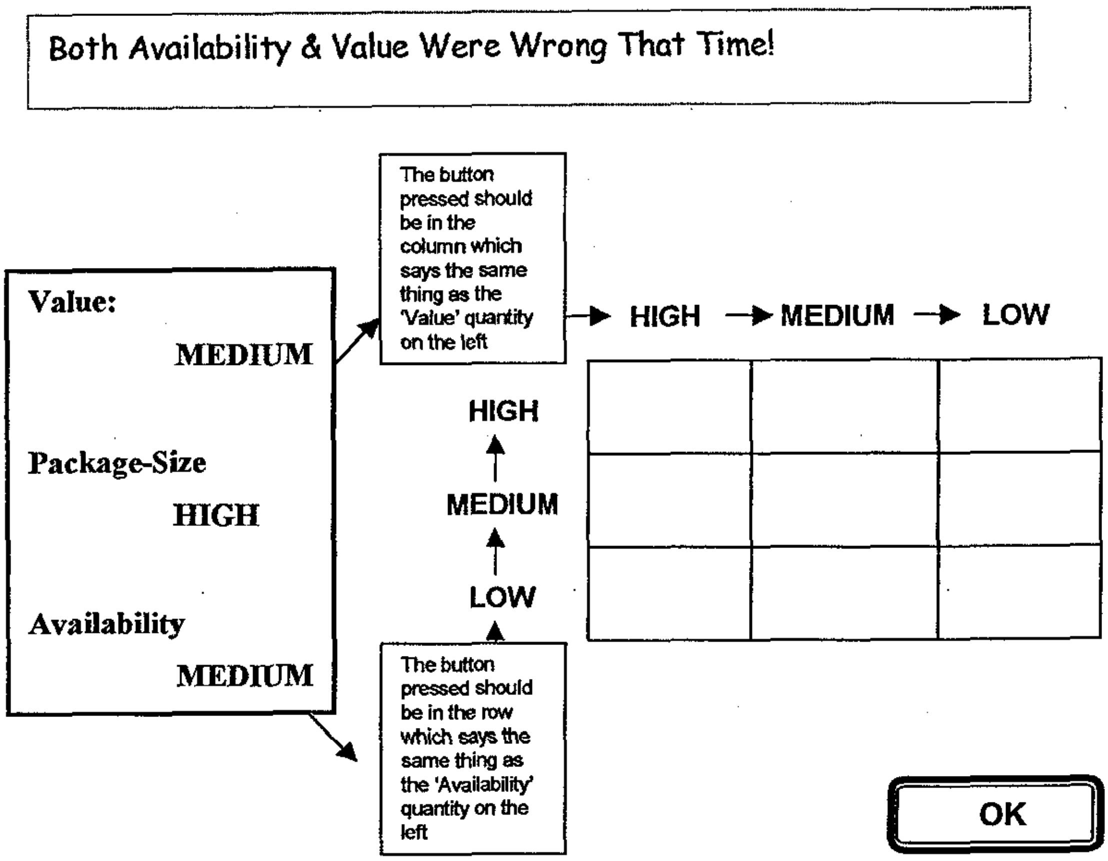
If you are happy with the explanations and instructions, then click on the button to start the Practice session !

OK

BACK

Appendix 6-7

Help Screen Example - Experiment 2



Appendix 8-1

Questions – Experiment 5

(First letter denotes the part [a, b, c or d] in which the question appeared) (Number denotes the number [1,2 or 3] of variables the question probes)

Part A

aA1 Which company has the highest value?

aB1 Which company has the lowest availability?

aC1 Do any of the following companies have a low Package Size?

aD1 The company 'Rocks Fridges' has just launched on the Stock Market. As yet however the market is still cautious and the shares have a high availability rating. Which of the companies below is it likely to be?

aE2 The conditions of the market are such that the best companies to buy are those with a low Package-size and low availability. Which of the companies shown is the most suitable?

aF2 'Videotica' the pioneering company of Video-on-demand is just about to launch its services using conventional telephone lines. A good number of investors are interested and Availability is low. Despite this the Market cautiously only rates the Value as medium. Which of the companies shown is it likely to be?

aG2 Wino's the pub chain are a company with medium Package-Size and medium availability. Of the companies shown below which is representative of Wino's?

aH2 Which of the companies below is of high value and medium Package-size?

aI3 The current market climate demands that low value companies are snapped up as quickly as possible. In addition to this its desirable that the shares are of high Availability and high Package-Size. Which of the following companies is the most suitable?

aJ3 Which of the companies shown has a low Package-size, low Value and high Availability?

aK3 Which company has a high Value, medium Availabilty and low Package-Size?

aL3 Your ideal company has a high availability, a low value and a low Package Size. Are any of the below suitable?

aO1 You are looking to buy a very small number of shares in the Hosiery Industry. The companies below are all Hosiery companies, but one is more suited to your purpose than the others. Which one is it?

aP1 One of the companies below is almost entirely privately owned with few of the shares being available on the open market. Which of the companies featured below will it be?

aQ1 The annual report for the car firm 'TVS' reveals that profits are five times higher than anticipated. The market is enraptured with this performance. Which if any of the companies below is TVS?

aR1 Shares of Centraco the gas company are rated as medium in terms of purchasing flexibility. Which of the below might be Centraco?

aS2 'ZappoGen' has just patented the secret of nuclear fusion, meaning that they are the only company allowed to produce energy in this revolutionary new manner. The Stock Market is widely enthusiastic. Which of the companies below is it most likely to be?

aT2 'Campico' the tent making company recently had a severe down-turn in profits which is still reflected in the price of the company. There are however only very few shares of this company available on the Stock Market as the majority of them are owned by the company's founders. Which company is it?

aU2 Which of the companies below does the Stock Market appear to be most keen about?

aV2 The world's largest airline 'Air Cymru' has decided to undertake an aggressive campaign of expansion and buy out as many small airlines as possible. Shares in small airlines have therefore become very rare and expensive. Which of the companies shown is likely to be an airline?

aW3 The Bonzai Branch Cutters Company has just been floated on the Stock Market. Every single one of its shares is available to be bought in packages as small as desired. The shares are expensive. Which of the below is it?

aX3 'Ring-A-Ding' phones has just floated on the Stock Market. Every one of its shares is available to be bought in packages as small as desired. The shares are expensive. Which of the below is it?

aY3 Which of the companies represented below is very cheap, rare and highly inflexible regarding purchasing?

aZ3 Which of the companies shown below is cheap, highly flexible regarding purchasing, and widely available?

Part B

bA1 You are looking for the company with the highest availability of shares. Which is it?

bB1 Which company's shares are grouped in the largest package size?

bC1 The conditions of the market are such that the best companies to buy are those with low Availability. Which of the companies shown below is suitable?

bD1 Which of the companies below has the highest value?

bE2 Which of the companies shown has both the highest Package-size and Value?

bF2 'Icypops' the country's largest Ice Cream maker is rated as medium in Availability and medium in Value. Which of the below is it?

bG2 T&A the Clothing company have just had their new range endorsed by Tiffany Beers the Teen Pop Star. Share value of the company is therefore high and share availability low. Are any of the below T&A?

bH2 Tiffany Beers the teen pop-star has been especially active lately and has just signed a new contract with Pony Records. Pony's shares have a medium Package Size, and are now high in Value. Which of the below is likely to represent the company?

bI3 One of the companies shown below has a high Value, high Package-size and high Availability. Which one is it?

bJ3 The current financial climate means that the optimum choice for your venture into the Stud Farming line of business will be a company which is currently of medium value, high Package-size and high Availability. Which company of those shown below do you choose?

bK3 Which company has a low Value, high Availability and medium Pacakge Size?

bL3 The conditions of the market are such that the best companies to buy are those with high Availability, lowValue and medium Package Size. Which of the companies shown below are suitable?

bO1 Which of the companies shown below is perceived as most valuable by the market?

bP1 The country's leading radio station 'Bland FM' has gone into a state of shock on hearing that the USA's leading Shock Jock has signed a deal with their main rival 'Bland FM' shares therefore go on to hit a record Stock Market low. Which of the below is Bland FM?

bQ1 'Q Cables' the telecommunications company is just about to be floated on the Stock Market but as yet none of the shares have been sold. Which of the below is 'Q Cables' ?

bR1 The household products maker 'Beckitt & Polman' has been judged by the market to have a 'loss of direction'. Shareprices have tumbled to their lowest level ever. Which company is it likely to be?

bS2 After the announcement that 'Breakdown Ltd.' is about to go bankrupt, shareholders are falling over each other to get rid of their shares. Which of the companies shown below is Breakdown Ltd.?

bT2 'Pharmaco Drugs' has recently developed a universal cure for cancer. Share prices of the company rocket and the number of shares available on the market is correspondingly low as buyers rush to grab as many of the shares as possible. Which of the companies below is 'Pharmaco'?

bU2 You are looking to make an entrance into the airline industry by taking over a currently operating company. Ideally you are looking for one which is undervalued. Which of the below best suits your requirements?

bV2 News 2000 the publishing conglomerate has recently announced a number of mergers about which the market is extremely keen. Which of the companies below is likely to be News 2000?

bW3 You are looking for the company that offers greatest flexibility in the amount of shares which can be bought, is relatively cheap and is predominantly privately owned. Which company should you choose?

bX3 'Mulberry' the luxury goods brand has just announced a Japanese deal that could boost its sales tenfold in the next year. Investors are ecstatic especially given the high purchasing flexibility that the company has always offered. Which company below is 'Mulberry'?

bY3 Which of the companies shown below is expensive, medium in rating of purchasing flexibility and has shares which are extremely scarce in the current market?

bZ3 'Burtons Biscuits' have had a mediocre year. Consequently their share price is only in the middle range, as is the availability of the company's shares. Their shares have only ever been available in large groups. Which company is Burtons?

Part C

cA1 Which company has the highest value?

cB1 You are looking for a company with high availability. Are any of the companies below suitable?

cC1 The best company for you to invest in at the moment would have a high Package Size. Are any of the candidates below suitable?

cD1 Which company has medium availability?

cE2 You are on the lookout for low valued companies with a high Availability. Which company would be the most advisable to invest in?

cF2 'Blocks R Us' the Property developer has managed to survive the recent depression and now the company's shares are rated as high in value and low in availability. Which company is it?

cG2 Which company has a medium Value and low Availability?

cH2 Panchester United's shares have always sold in medium sized amounts. Now the glory days of the team are at an end and the share value is low. Which of the below is Panchester Utd ?

cI3 Which of the companies below has no low rated variables?

cJ3 Which of the companies below has no medium rated variables?

cK3 The conditions of the market are such that the best companies to invest in are those with medium Availability, high Value and medium Package-Size. Which of the companies shown below are suitable?

cL3 'Digberts', suppliers of dog collars to the Royal Family is a company which has a medium Value, medium availability and low Package-Size. Which of the below is it likely to be?

cO1 Which of the companies shown below is perceived as least valuable by the market?

cP1 Which of the companies below is least flexible in terms of purchasing flexibility?

cQ1 Terence Toopan the restaurant magnate has just opened another mass eaterie in the trendiest area of the Capital. The market is saturated however and the share value of the company is found only to lie in the middle range. Which of the below is it?

cR1 Of the three companies shown below, you wish to choose the one which offers greatest flexibility in terms of the number of shares you can buy in one transaction. Which of the three is most suitable?

cS2 After the disastrous launch of the new toy range 'Make Your Own Spears', the share price of 'Tongo Toys' plummets. Shareholders abandon in droves. Which company is it likely to be?

cT2 Gill Bates owns the vast majority of the Computer company 'Softicomp'. A small proportion is freely available on the open market. The company is going from strength to strength and the share value reflects this. Which of the companies shown is 'Softicomp' likely to be?

cU2 Which of the companies shown below is perceived as least desirable by the market?

cV2 A curious set of Stock Market conditions means that you are looking for 'hidden stars' – companies offering greatest purchasing flexibility which are not rated as high value Availability is unimportant. Which company do you choose?

cW3 Which of the companies below is medium in price, widely available and highly inflexible in terms of purchasing flexibility?

cX3 Which of the companies below is cheap, rare and highly flexible regarding amount of shares needing to be purchased?

cY3 Which of the companies shown below is most flexible in terms of shares which can be bought at one time, and is medium priced with widely available shares?

cZ3 'Tearaway Tyres' have had an excellent year. Consequently their shares price is the highest in the sector as is the availability of the company's shares. Their shares have always been sold in medium sized amounts. Which of the depictions below represent the company?

Part D

dA1 Which company has the highest Value?

dB1 Which company does not have a medium share availability?

dC1 Which of the companies shown below has a medium value?

dD1 Do any of the companies below have medium Package size?

dE2 Which of the companies featured below has both medium availability and medium package size?

dF2 Boggalogs the Baking Company has a medium value and low availability. Of the companies below, which is it?

dG2 Rocta Copters the new and wild Helicopter company has not been doing so well recently after the launch of their one rotored Helicopter. As most shares are privately held, Availability is low as is share Value. Which of the companies below is it?

dH2 Nice 'n' Bright paints is about to launch on the Stock Market. Share Value will be high as will Availability. Which of the below represents Nice 'n' Bright?

dI3 'Slibbert & Dogsbox' the high-class catering chain are currently a company with a high Value, medium Availability and medium Package-size. Which company is it?

dJ3 The conditions of the market are such that the best companies to buy are those with high Availability, medium Value and low Package Size. Which of the companies shown below are suitable?

dK3 One of the companies shown below has a high availability, medium Package-size and low Value. Which one?

dL3 One of the companies shown below has a low availability, medium Package-size and low value. Which one?

dO1 'Netserve' the free Internet Service Provider is the first company of its kind onto the Stock Market. The internet is perceived by traders as having a great future and the Value of the company reflects shows this. Which of the companies below is 'Netserve'?

dP1 Oxaco the Oil Exploration company has recently discovered a vast new Oil field which should ensure that it is the leading supplier of oil, well into the 21st century. Competition for the shares is so intense on the trading floor that fights break out. Which of the companies is Oxaco likely to be?

dQ1 Elvic the Bottled water company is shocked when it is discovered that the source of their Spring water runs past a Toxic waste dump. Shareholders are all desperate to get rid of their shares. Which company is it likely to be?

dR1 Walters the bicycle company is rated as low in terms of purchasing flexibility. Which of the following companies is Walters likely to be?

dS2 The Luxus Hotel chain has just sold its flagship hotel to its rival in an attempt to prevent bankruptcy. Practically all shareholders are trying to sell their shares and the share value is as low as it's possible to be. Which of the companies below is it likely to be?

dT2 Bumblers Bank has just acquired a new dynamic chief executive. The market is enthusiastic pushing share values to record levels. Shares as a consequence have never been so difficult to acquire. Which of the below is Bumblers?

dU2 Pokers the Luxury pen producers have just announced annual results which are somewhat disappointing. Are any of the companies below likely to be Pokers?

dV2 Chugger Rail the newly formed train company has performed appallingly over the last few months. Share Value is therefore at an all time low and noone is interested in holding onto their shares. Which of the companies below is it?

dW3 Your ideal company is one which is currently hard to get hold of, extremely cheap and available to be bought in whatever share group size you desire. Which of the companies below fits the description?

dX3 You are looking for a company which offers the highest level possible of purchasing flexibility, is widely available and highly valued. Are any of the companies below suitable?

dY3 Biggleswell the Booksellers is a highly valued company. Traditionally their shares have always been sold in highly flexible amounts. Today there are only a very small proportion of the company's shares available. Which company is Biggleswell?

dZ3 You are looking for the company that offers least flexibility in the amount of shares which can be bought, is relatively expensive and is predominantly privately owned. Which company do you choose?

Appendix 8-2

Instructions (Incorporating 'Normal' Analogy Keycard)– Experiment 5

Your Name :

Welcome to Financia - Land of Opportunity !

This purpose of this program is to evaluate your possible potential as a 'Share Scout' in Financia's Stock Market.

The job of a Share Scout is to search for companies which are going to make you the most money.

This used to be a difficult task in the days before computers, but now it is much easier. The computer automatically tells you what qualities in a company you are looking for, and presents you with a set of possible choices. Your task is to look at these companies and decide if one of them best fits the bill, or if none of them do. The session today will be split into four parts. In each part there will be 24 questions to answer. At the end of each part you will then be told how well you did, and will have a few minutes to recover!

The next few pages will explain how the information about each company will be presented and what it means. Before the task starts you will have as much time as you like to read through these instructions. Before you go on though, could you please make sure your name is filled in, in the box in the top right hand corner......

OK

In this somewhat simplified scenario, there are <u>three</u> variables which determine how suitable a company is to you. These are VALUE, AVAILABILITY, and PACKAGE SIZE:

<u>VALUE</u>

VALUE refers to how much a company is worth in relation to other companies of the same type and size. A company which is about to go Bankrupt for example or which is perceived in any way as being undesireable, will have a low Value. Similarly, a company which is perceived as being desireable will have a high Value.

<u>AVAILABILITY</u>

A company will have a different amount of shares available on the open market at different times. When lots of people want to sell their shares then there will be lots of shares available, and the company will have a high Availability. If lots of people are holding on to their shares in a particular company and don't want to sell then the company will have a low availability.

<u>PACKAGE-SIZE</u>

Company shares are not sold singly but are sold in groups otherwise known here as 'Packages'. For historic reasons in Financia's Stock Market, some companies require that a large number of shares are bought in a single transaction while others only require that a small amount be sold in a single transaction. Companies that require a lot of shares to be bought at one time therefore have a high Package-Size, while companies that only require shares to be bought in small groups will have a low Package-Size.

BACK

OK

What Do The Computer Visualisations Show?

The way in which VALUE, AVAILABILITY and PACKAGE SIZE are shown by the computer will now be described:

Each company is represented by a glass. The glass (or company) contains balls which represent groups of shares (ie Packages). The company can be thought of as a container for the shares much as a glass could be a container for balls in real life.

The balls themselves represent the shares or to be more precise - the groups of shares, and can be seen to be more or less valuable according to what metal they are made of whether it is Bronze as most valuable, Silver for medium value or Gold as least valuable. The group size that the shares are bought in are then shown by the size of the balls. Large groups of shares are shown by small balls and small groups of shares by large balls.

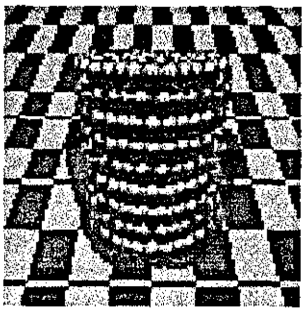
The company then, is represented by the framework of the glass, and the shares which make up the company by the balls in the glass. The amount of shares available to you is shown by how full of balls the glass is. If there are only a small amount of shares available to you, then the glass will appear full of balls, and if the maximum amount is available then the glass will appear only slightly full.

To recap then: There are three ways in which companies differ from each other in this exercise - VALUE, AVAILABILITY & PACKAGE-SIZE. These are shown by METAL TYPE, LEVEL OF BALLS IN THE GLASS, & SIZE OF BALLS. Each of the these 3 variables can then be either low, medium or High.

This will now be demonstrated on the next Page.........

VALUE

Value is shown by the type of metal which the balls are made of: Bronze, Silver or Gold.



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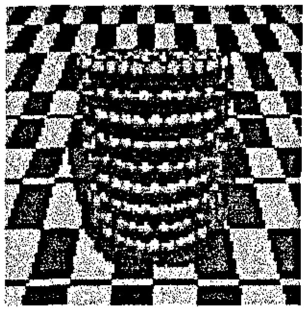

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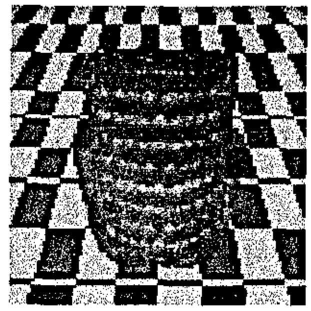
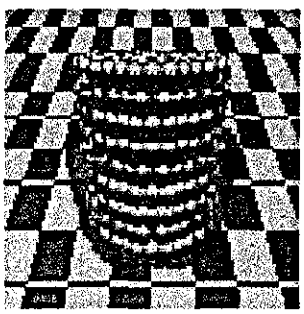


Low

AVAILABILITY

Availability is shown by the height of the balls in the glass: 1/3 Full, 2/3 Full, or Full



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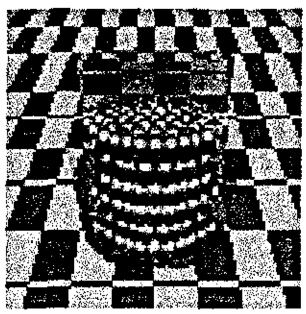

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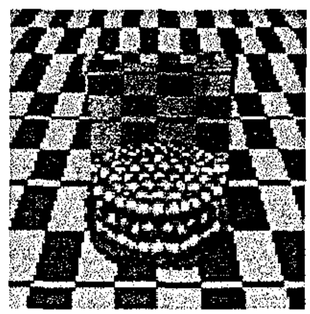
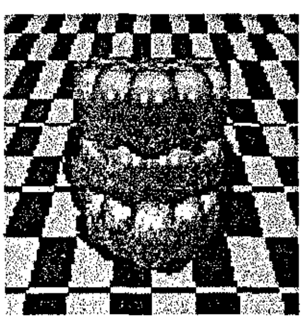


Low

PACKAGE SIZE

Package Size is shown by the size of the balls: Small, Medium or Large



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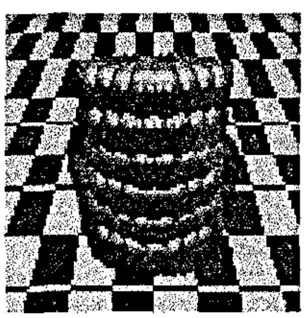
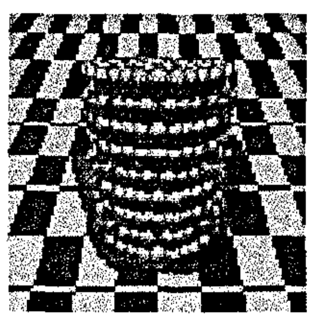


Medium



Low

BACK

OK

How Financia's Stock Market works

Financia's stock market is slightly different to those found in other countries. As already stated, shares here have to be bought in different sized amounts - known as Package-sizes.

Supply & Demand

A short explanation on supply and demand also needs to be given and how it works in this scenario- The stock market here works on the principle of supply and demand. If there is a heavy demand for shares in a company - the number of shares available will decrease while the price of those shares will increase. This is because people will pay a higher price for shares that they want badly.

If on the other hand if the opposite is true and investors are trying to get rid of their shares (which might happen if a company is known to have performed badly) then the availability of these shares will increase and the value of these shares will fall. Noone after all wants to pay a high price for shares in a company which isn't doing well.

Availability and Value are therefore linked in this way. Package-Size is irrelevant to this rule and makes no difference.

That's all you need to know about Financia's Stock Market. You will be told exactly what you are looking for as you answer each question.

BACK

OK

There will now follow a practice session. If you answer any of the questions incorrectly the computer will explain how the correct answer should be arrived at. Once you have answered 10 questions correctly the practice session will end and you will be able to start the proper test.

A 'key' will be available to you at all times should you need it. This is on the card next to you.

The practice sessions are not 'marked' or timed and are just meant to show you how the test works. Read each question and once you've understood it press the reveal button to show your options.......

If you are happy with the explanations and instructions, then click on the button to start the Practice session !

START!

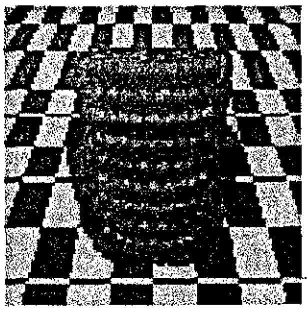
BACK

Appendix 8-3

Reversed Analogy Condition Keycard – Experiment 5

VALUE

Value is shown by the type of metal which the balls are made of: Gold, Silver or Bronze.



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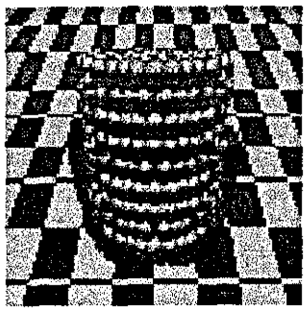
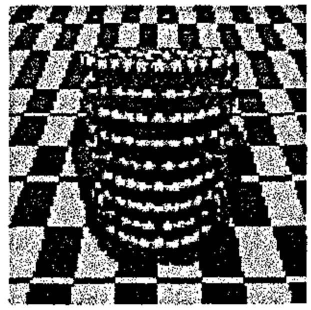


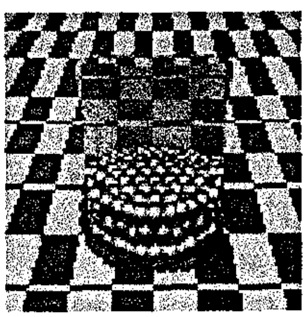
Medium



Low

AVAILABILITY

Availability is shown by the height of the balls in the glass: Full, 2/3 Full, or 1/3 Full



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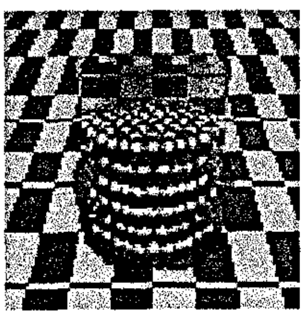
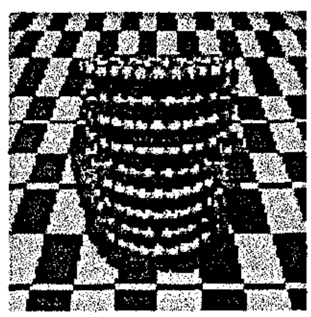


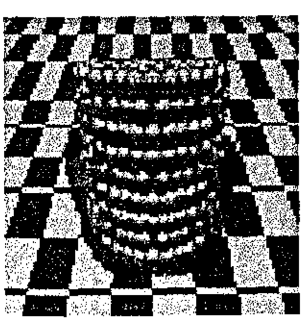
Medium



Low

PACKAGE SIZE

Package Size is shown by the size of the balls: Large, Medium or Small



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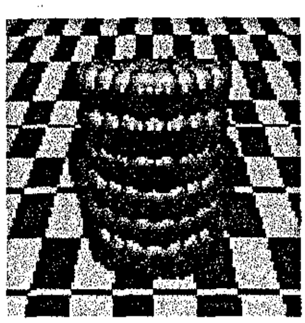
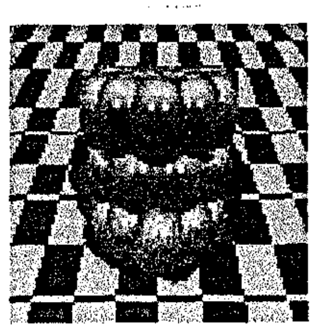


Medium



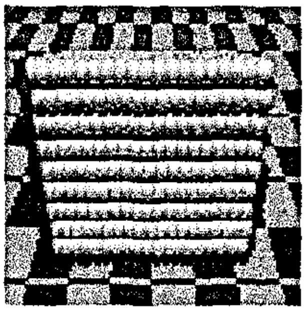
Low

Appendix 8-4

'Normal' Non-Analogy Condition Keycard – Experiment 5

VALUE

Value is shown by the type of metal which the balls are made of: Bronze, Silver or Gold.



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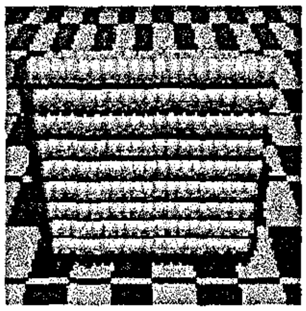

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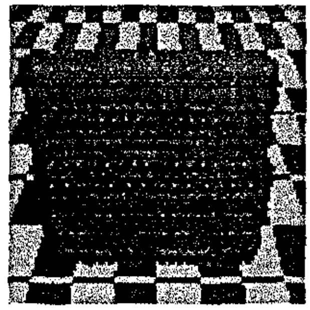
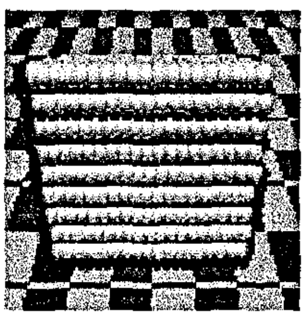


Low

AVAILABILITY

Availability is shown by the height of the balls against the wall:



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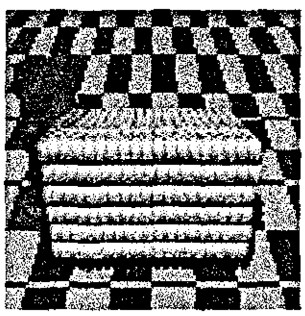
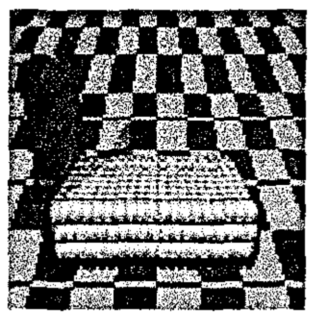


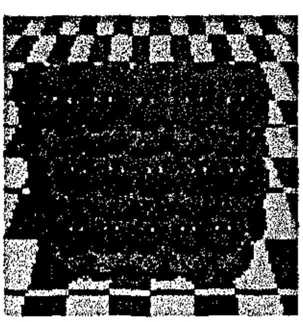
Medium



Low

PACKAGE SIZE

Package Size is shown by the size of the balls: Small, Medium or Large



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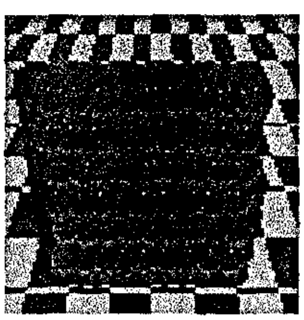
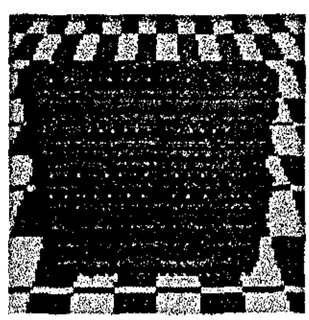


Medium



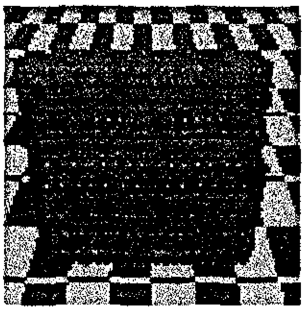
Low

Appendix 8-5

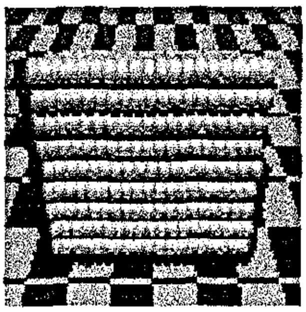
'Reversedl' Non-Analogy Condition Keycard – Experiment 5

VALUE

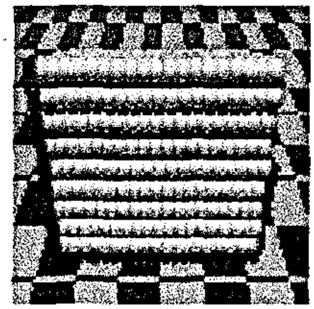
Value is shown by the type of metal which the balls are made of: Bronze, Silver or Gold.



High



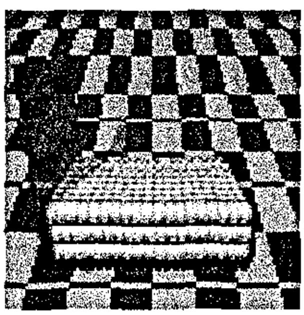
Medium



Low

AVAILABILITY

Availability is shown by the height of the balls against the wall:



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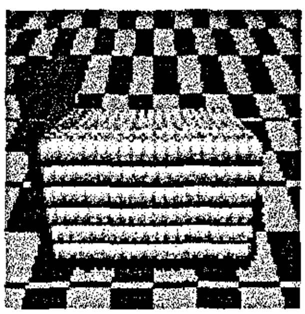
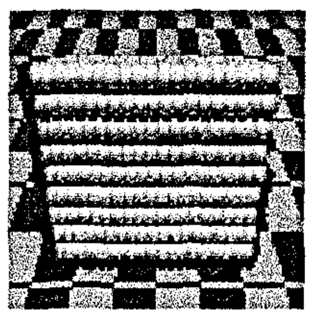


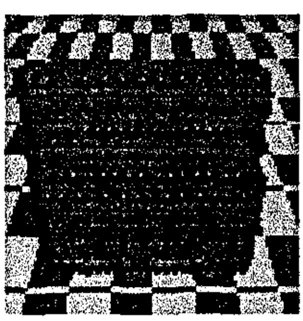
Medium



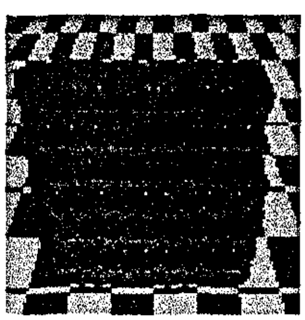
Low

PACKAGE SIZE

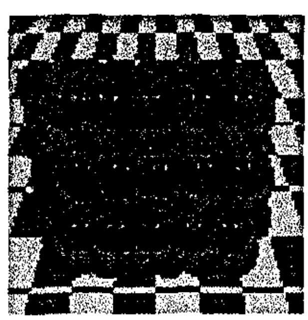
Package Size is shown by the size of the balls: Small, Medium or Large



High



Medium



Low

Appendix 8-6

Hypercard Training Stack Script – Experiment 5

```
on openStack
  global i, ii, iii, cardNo, trainbox
  hide menuBar
  put empty into i
  put empty into ii
  put empty into iii
  put empty into cardNo
  put empty into trainbox
  put empty into cd field "array" of card "control card"
  orderise
end openStack

--CLOSE WINDOWS
on x
  global i, ii, iii
  close window i
  close window ii
  close window iii
end x

on e
  global e1, e2
  close window e1
  close window e2
end e

on hideous
  hide button "1"
  hide button "2"
  hide button "3"
  hide button "NONE"
end hideous


-- -- CREATE a random presentation list
-- on randomise
-- put empty into randomlist
-- put empty into cd field "array" of card "control card"
-- put the itemDelimiter into delim
-- repeat until the number of items in randomlist is 10
-- get random of 10
-- if (delim&it&delim) is not in (delim&randomList) then
-- put it & delim after randomList
-- put 16-it & return after cd field "array" of card "control card"
-- end if
-- end repeat
-- delete last char of randomList
-- end randomise

-- CREATE an ordered presentation list
```

```
on orderise
  put "7" & return into cd field "array" of card "control card"
  put "8" & return after cd field "array" of card "control card"
  put "9" & return after cd field "array" of card "control card"
  put "10" & return after cd field "array" of card "control card"
  put "11" & return after cd field "array" of card "control card"
  put "12" & return after cd field "array" of card "control card"
  put "13" & return after cd field "array" of card "control card"
  put "14" & return after cd field "array" of card "control card"
  put "15" & return after cd field "array" of card "control card"
  put "16" & return after cd field "array" of card "control card"
end orderise


--THE REVEAL BUTTON
on w
  global i, ii, iii
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put "REV " & the name of this card & tab & tab && elapsedTime &
return after cd field "RecordTime" of card "Results"
  show window i
  show window ii
  show window iii
  show button "1"
  show button "2"
  show button "3"
  show button "none"
end w


-- RIGHT ANSWER
on rightrandom
  global cardNo
  if line 1 of cd field "array" of card "control card" is empty then
    put "37" into CardNo
  else
    put line 1 of cd field "array" of card "control card" into CardNo
    delete line 1 of cd field "array" of card "control card"
  end if
  go card cardNo
end rightrandom


-- WRONG ANSWER
on nextrandom
  global cardNo
  global trainbox
  put cardNo into add10box
  put cardNo into trainbox

  if line 1 of cd field "array" of card "control card" is empty then
    put "37" into CardNo
  end if
```

```
 if trainbox < 17 then
   add 20 to trainbox
 else
   add 10 to trainbox
 end if

 if add10box < 17 then
   add 10 to add10box
 else
   subtract 10 from add10box
 end if

 put add10box & return after cd field "array" of card "control card"
 put line 1 of cd field "array" of card "control card" into CardNo
 delete line 1 of cd field "array" of card "control card"
 go card trainbox
end nextrandom


on joinTest
  global cardno
  go card cardNo
end joinTest

on openCard
  global result
  startRecord
end openCard

on closeCard
  endRecord
end closeCard


//REMOVE close window i, ii, iii

on x
  global i, ii, iii
  close window i
  close window ii
  close window iii
end x


--RECORD the moment the current card is opened
on startRecord
  global startTime
  put the ticks into startTime
end startRecord

on endRecord
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put the name of this card & tab & tab && elapsedTime & return after
cd field "RecordTime" of card "Results"
```

```
end endRecord


on saveData
  global Data2


  -- putting the name, time and date into the desktop File name?

  put cd field "subjectId" of card "Introl" into File2
  put "-RVTrain-" & the date after File2
  open file File2


  -- putting the name, time and accuracy into the saved results File?

  put "TRAINING ANSWERS - Metaphor REVERSED" && return into Data2
  put the date && the time && return after Data2


  put cd field "subjectId" of card "Introl" after Data2
  put return & return & cd field "Data" of card "Results" after Data2
  put return & cd field "RecordTime" of card "Results" after Data2

  write Data2 to file File2


  --clear the data recording fields for next subject

  put empty into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Introl"

  go "Part Ar"

end saveData
```

Appendix 8-7

Hypercard Stack Script - Experiment 5

```
On open stack
      Global I, ii, iii, result, cardNo, count
      Hide menubar
      Put empty into result
      Put empty into i
      Put empty into ii
      Put empty into iii
      Put empty into count
      Put empty into cd field "array" of card "control card"
      Put empty into cd field "resbox" of card "rescard"
      Randomise
End open stack

--create a random presentation list
on randomise
      put empty into randomList
      put the itemDelimeter into delim
      repeat until the number of items in randomList is 24
            get random of 24
            if (delim&it&delim) is not in (delim&randomList) then
                  put it & delim after randomList
                  put 26-it & return after cd field "array" of card
"control card"
            end if
      end repeat
      delete last char of randomList
end randomise

--Advance to all cards in random list before moving on to end
on nextrandom
      global cardNo
      global count
      put empty into cd field "countbox"
      if line 1 of cd field "array" of card "control card" is empty
them put "26 into
            Card No
      Else
            Put line 1 of cd field "array" of card "control card" into
cardNo
            Delete line 1 of cd field "array" of card "control card"
            Add 1 to count
      End if
      Go card cardNo
      Put count into cd field "countbox"
End nextrandom

On x
      Global I, ii, iii
      Close window i
      Close window i
      Close window I
End x
```

```
On e
      Global e1, e2
      Close window i
      Close window i
      Close window I
End e

On hideous
      Hide button "1"
      Hide button "2"
      Hide button "3"
      Hide button "NONE"
End hideous

On openCard
      Global result
      StartRecord
End openCard

On closeCard
      EndRecord
End closeCard

--record the moment the card is opened
on startRecord
      global startTime
      put the ticks into startTime
end startRecord

on endRecord
      global result
      global decide
      global startTime
      global elapsedTime
      if decide = 2 then put the name of this card &&"-Correct" &
return after cd field "data" of card "results"
      if decide = 3 then put the name of this card & return after cd
field "data" of card "results"
      put empty into decide
      put ((the ticks - startTime)/60) into elapsedTime
      put the name of this card & tab & tab && elapsedTime & return
after cd field "RecordTime" of card "Results"
end endRecord

--Show Windows & Add Time

on w
      global I, ii, iii
      global startTime
      global elapsedTime
      put ((the ticks - startTime)/60) into elapsedTime
      put "REV" & the name of this card & tab && elapsedTime & return
after cd field "RecordTime" of card "Results"
      show window i
      show window ii
      show window iii
```

```
      show button "1"
      show button "2"
      show button "3"
      show button "NONE"
end w

on clear
      global, result, count
      put empty into result
      put empty into cd field "Data" of card "Results"
      put empty into cd field "RecordTime" of card "Results"
      put empty into cd field "subjectId" of card "Intro1"
      put empty into cd field "resbox" of card "rescard"
      put empty into count
      put empty into cd field "array" of card "control card"
end clear"


--Save Data

on saveData
      global Data2

--putting the name, time and date into the desktop file name

      put cd field "subjected" of card "Intro1" into File2
      put "-PartA-" && the date after File2

--putting the name, time and accuracy into the saved results File

      put "TEST ANSWERS: Metaphor Condition - Part A && return into
Data2
      put the date && the time && return after Data2

      put cd field "subjectId" of card "Intro1" after Data2
      put return & return & cd field "Data" of card "Results" after
Data2
      put return & cd field "RecordTime" of card "Results" after Data2

      write Data2 to file File2


--clear the data recording fields for next subject

      put empty into result
      put empty into cd field "Data" of card "Results"
      put empty into cd field "RecordTime" of card "Results"
      put empty into cd field "subjectId" of card "Intro1"
      put empty into cd field "resbox" of card "rescard"

end saveData
```

Appendix 8-8

HYPERCARD Card Script - Experiment 5

```
On opencard

      Hideous

      Global I
      Global ii
      Global iii

      Put "B2LH.pict" into i
      Put "S6HH.pict" into ii
      Put "B6LH.pict" into iii

      Picture I, file, rect, false, 8
      Picture I, file, rect, false, 8
      Picture I, file, rect, false, 8

      Set the loc of window I to "50, 150"
      Set the loc of window I to "290, 150"
      Set the loc of window I to "530, 150"

End openCard
```

Appendix 8-9

HYPERCARD Button Script - Experiment 5

Right Answer

```
On mouseUp
      Global I,ii,iii
      Global decide
      Global result
      Close window I
      Close window ii
      Close window iii
      Add 1 to result
      Put 2 into decide
      NextRandom
End mouseUp
```

Wrong Answer

```
On mouseUp
      Global mcbox
      Put the short name of me into mcbox
      WrongRandom
End mouseUp
```

Appendix 8-10

HYPERCARD Raw Data - Experiment 5

Test Answers: Metaphor Condition – Part D
20/10/99 5:03pm
Participant 2

card "dX3"	Correct
card "dK3"	Correct
card "dJ3"	Correct
card "dQ1"	
card "dF2"	Correct
card "dE2"	Correct
card "dI3"	Correct
card "dG2"	
card "dS2"	Correct
card "dY3"	Correct
card "dA1"	
card "dT2"	Correct
card "dZ3"	
card "dH2"	Correct
card "dD1"	Correct
card "dP1"	Correct
card "dB1"	Correct
card "dO1"	Correct
card "dC1"	Correct
card "dU2"	
card "dW3"	Correct
card "dV2"	Correct
card "dR1"	
card "dL3"	Correct

23 Total

card "Intro1"	105.066667
REV card "dX3"	117.733333
card "dX3"	120.55
REV card "dK3"	132.316667
card "dK3"	135.95
REV card "dJ3"	152.016667
card "dJ3"	154.15
REV card "dQ1"	168.733333
card "dQ1"	172.516667
REV card "dF2"	186.1
card "dF2"	187.233333

card "dE2"	205.916667
REV card "dI3"	221.316667
card "dI3"	225.116667
REV card "dG2"	239.25
card "dG2"	242.966667
REV card "dS2"	257.716667
card "dS2"	259.35
REV card "dY3"	275.233333
card "dY3"	280.716667
REV card "dA1"	285.216667
card "dA1"	290.733333
REV card "dT2"	303.216667
card "dT2"	307.066667
REV card "dZ3"	324.683333
card "dZ3"	330.9
REV card "dH2"	350.15
card "dH2"	352.366667
REV card "dD1"	359.45
card "dD1"	362.75
REV card "dP1"	381.6
card "dP1"	384.5
REV card "dB1"	391.65
card "dB1"	393.5
REV card "dO1"	406.316667
card "dO1"	407.5
REV card "dC1"	411.766667
card "dC1"	413.516667
REV card "dU2"	418.516667
card "dU2"	423.366667
REV card "dW3"	442.6
card "dW3"	447.05
REV card "dV2"	459.233333
card "dV2"	463.116667
REV card "dR1"	470.4
card "dR1"	476.55
REV card "dL3"	492.116667
card "dL3"	494.7

Appendix 8-11

Representations featuring In Each Question - Experiment 5

Question	Left Representation	Centre Representation	Right Representation
aA1	S6h	S3m	S3l
aB1	B2l	G3h	S6m
aC1	S3l	B6l	G2m
aD1	S6m	S6l	S6h
aE2	S2m	S2h	S2l
aF2	S2h	G2h	S3h
aG2	G3h	B3h	S3h
aH2	B3l	S2m	G2h
al3	S2m	G6l	B3h
aJ3	G2m	G2h	G2l
aK3	S3l	G3h	B2h
aL3	G2l	G3m	G6h
aO1	G6l	B6m	S6h
aP1	G2l	S2l	B2h
aQ1	B6l	B3h	B6h
aR1	G3h	S3h	B3h
aS2	G3h	G3l	S3l
aT2	S3l	S3m	S3h
aU2	S2l	G2l	S2m
aV2	S2h	G6l	B3m
aW3	B6l	S3l	G2l
aX3	S6h	G6h	B6h
aY3	G3m	G6m	G2m
aZ3	G3l	B2m	S3l

Question	Left Representation	Centre Representation	Right Representation
bA1	B2m	S3h	G6l
bB1	G3l	B2m	S6h
bC1	S6l	S2l	B3l
bD1	G3l	S3m	B3h
bE2	S3h	S2h	S6l
bF2	G2h	G2l	G2m
bG2	G6l	B3m	S2h
bH2	S3m	G2h	B6l
bI3	S6l	S6h	S6m
bJ3	S2l	B6h	G2l
bK3	G6l	S2m	B3h
bL3	B3l	B3m	B2m
bO1	B3m	B6m	B2m
bP1	S2h	G3m	B6l
bQ1	G3h	B2h	S6h
bR1	G2l	G3l	G6l
bS2	B2m	S3m	B6m
bT2	B2l	B3m	B2h
bU2	G6l	G3l	G2l
bV2	B6h	B2h	B3h
bW3	G6m	G6l	G6h
bX3	S3h	S3m	S3l
bY3	B2l	G3m	S3m
bZ3	S6m	S6h	B6m

Question	Left Representation	Centre Representation	Right Representation
cA1			
cB1			
cC1			
cD1			
cE2			
cF2			
cG2			
cH2			
cI3			
cJ3			
cK3			
cL3			
cO1			
cP1			
cQ1			
cR1			
cS2			
cT2			
cU2			
cV2			
cW3			
cX3			
cY3			
cZ3			

Question	Left Representation	Centre Representation	Right Representation
dA1			
dB1			
dC1			
dD1			
dE2			
dF2			
dG2			
dH2			
dI3			
dJ3			
dK3			
dL3			
dO1			
dP1			
dQ1			
dR1			
dS2			
dT2			
dU2			
dV2			
dW3			
dX3			
dY3			
dZ3			

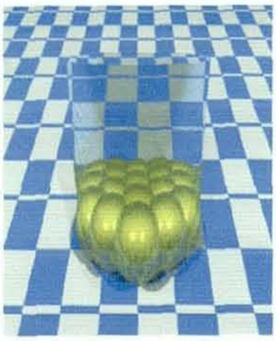
Appendix 8-15

Help Screen Examples – Experiment 5 (Analogy Reversed)

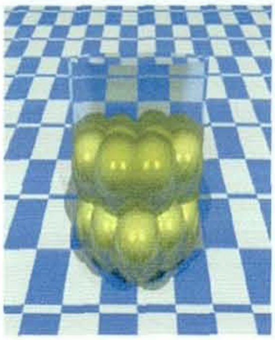
Availability Help

That wasn't the right option......

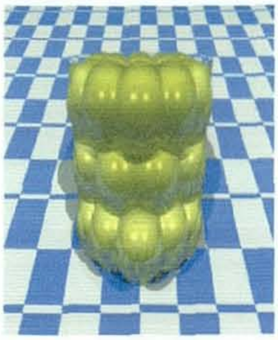
The question was looking at Availability of company shares. Availability describes the proportion of a company's shares which are available to you should you wish to buy them. Availability is shown by how high the stack of balls stands against the glass wall.



Low - High Availability



Medium - Medium Availability



Low - Low Availability

OK

Package-Size Help

That wasn't the right option......

Here the question is looking at Package-Size. Package Size refers to the size of the groups of shares or 'Packages' in which shares for each company have to be bought. Package-Size is shown by the size of the balls.

Small - High Package-Size

Medium - Medium Package-Size

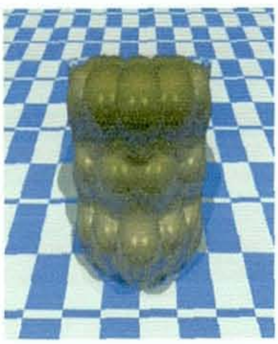
Large - Low Package-Size

OK

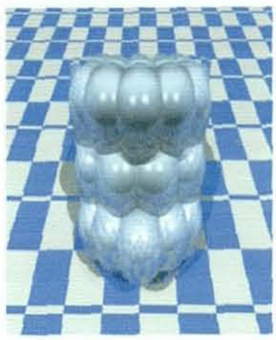
Value Help

That wasn't the correct option......

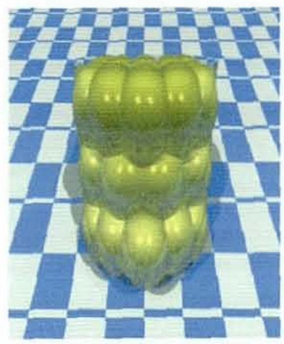
Here the question is looking at Value of the shares. Value is a relative term worked out by the computer. It describes how much shares of a company are worth in comparison to shares in other similar companies. Value is shown only by the metal the balls are made of.



Bronze - High Value



Silver - Medium Value



Gold - Low Value

OK

Availability &Value Help

That wasn't the correct option...

If a company is doing well then Investors will be keen to buy shares in it. This will be low as the shares are snapped up. Value of the shares will also be high as value is determined by how desirable investors see a particular company as being.

Package-Size is unimportant in this situation

Here is an example of a Company which has a

Low Availability
High Value

OK

Appendix 9-1

Instructions – Experiment 6

Your Name:

Welcome to Financia - Land of Opportunity !

This purpose of this program is to evaluate your possible potential as a 'Share Scout' in Financia's Stock Market.

The job of a Share Scout is to search for companies which are going to make you the most money.

This used to be a difficult task in the days before computers, but now it is much easier. The computer automatically tells you what qualities in a company you are looking for, and presents you with a set of possible choices. Your task is to look at these companies and decide if one of them best fits the bill, or if none of them do. The session today will be split into four parts. In each part there will be 24 questions to answer. At the end of each part you will then be told how well you did, and will have a few minutes to recover!

The next few pages will explain how the information about each company will be presented and what it means. Before the task starts you will have as much time as you like to read through these instructions. Before you go on though, could you please make sure your name is filled in, in the box in the top right hand corner......

OK

In this somewhat simplified scenario, there are three variables which determine how suitable a company is to you. These are VALUE, AVAILABILITY, and PACKAGE SIZE:

VALUE

VALUE refers to how much a company is worth in relation to other companies of the same type and size. A company which is about to go Bankrupt for example or which is perceived in any way as being undesireable, will have a low Value. Similarly, a company which is perceived as being desireable will have a high Value.

AVAILABILITY

A company will have a different amount of shares available on the open market at different times. When lots of people want to sell their shares then there will be lots of shares available, and the company will have a high Availability. If lots of people are holding on to their shares in a particular company and don't want to sell then the company will have a low availability.

PACKAGE-SIZE

Company shares are not sold singly but are sold in groups otherwise known here as 'Packages'. For historic reasons in Financia's Stock Market, some companies require that a large number of shares are bought in a single transaction while others only require that a small amount be sold in a single transaction. Companies that require a lot of shares to be bought at one time therefore have a high Package-Size, while companies that only require shares to be bought in small groups will have a low Package-Size.

BACK

OK

What Do The Computer Visualisations Show?

The way in which VALUE, AVAILABILITY and PACKAGE SIZE are shown by the computer will now be decribed:

Each company is represented by a glass. The glass (or company) contains balls which represent groups of shares (ie Packages). The company can be thought of as a container for the shares much as a glass could be a container for balls in real life.

The balls themselves represent the shares or to be more precise - the groups of shares, and can be seen to be more or less valuable according to what metal they are made of whether it is Gold as most valuable, Silver for medium value or Bronze as least valuable. The group size that the shares are bought in are then shown by the size of the balls. Large groups of shares are shown by large balls and small groups of shares by small balls.

As the company is represented by the framework of the glass, and the shares which make up the company by the balls in the glass, the amount of shares available to you is shown by how full of balls the glass is. If there are only a small amount of shares available to you, then only a few balls will be visible, and if the maximum amount is available then the glass will appear full of balls all of which are available to you.

To recap then: There are three ways in which companies differ from each other in this exercise - VALUE, AVAILABILITY & PACKAGE-SIZE. These are shown by METAL TYPE, LEVEL OF BALLS IN THE GLASS, & SIZE OF BALLS. Each of the these 3 variables can then be either low, medium or High.

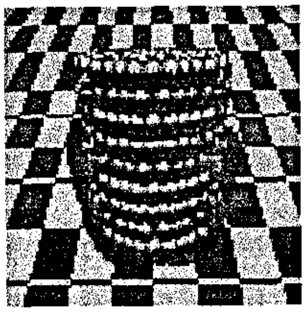
This will now be demonstrated on the next Page.........

BACK

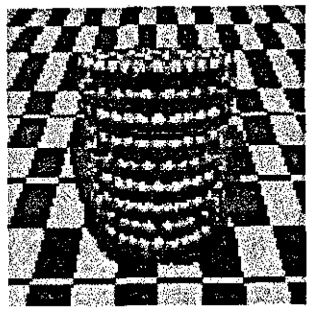
OK

VALUE

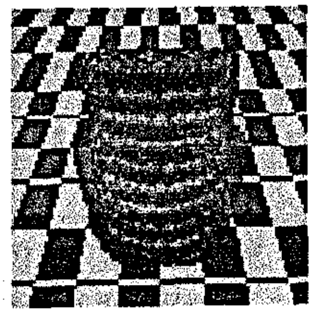
Value is shown by the type of metal which the balls are made of: Gold, Silver or Bronze.



High



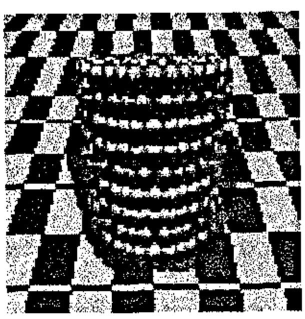
Medium



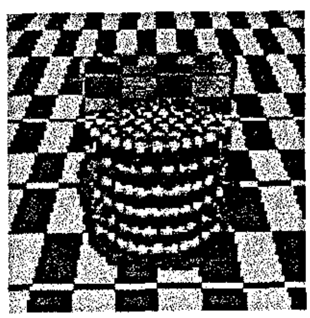
Low

AVAILABILITY

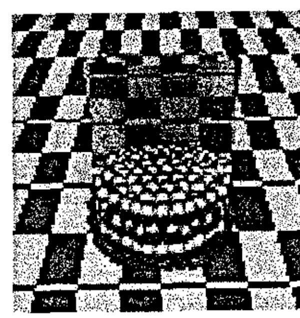
Availability is shown by the height of the balls in the glass.



High



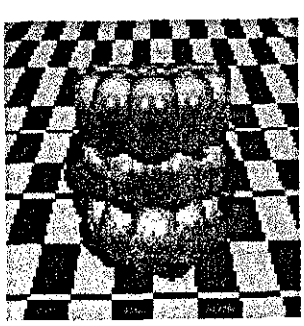
Medium



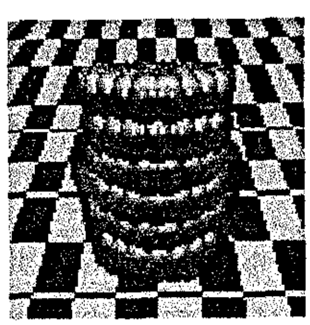
Low

PACKAGE SIZE

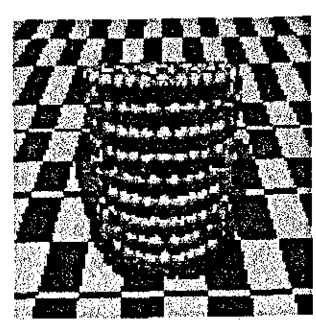
Package Size is shown by the size of the balls



High



Medium



Low

BACK

OK

How Financia's Stock Market works

Financia's stock market is slightly different to those found in other countries. As already stated, shares here have to be bought in different sized amounts - known as Package-sizes.

Supply & Demand

A short explanantion on supply and demand also needs to be given and how it works in this scenario- The stock market here works on the principle of supply and demand. If there is a heavy demand for shares in a company - the number of shares available will decrease while the price of those shares will increase. This is because people will pay a higher price for shares that they want badly.

On the other hand if the opposite is true and investors are trying to get rid of their shares (which might happen if a company is known to have performed badly) then the availability of these shares will increase and the value of these shares will fall. Noone after all wants to pay a high price for shares in a company which isn't doing well.

Availability and Value are therefore linked in this way. Package-Size is irrelevant to this rule and makes no difference.

That's all you need to know about Financia's Stock Market - however you will be told exactly what you are looking for as you answer each question.

BACK

OK

There will now follow a practice session. If you answer any of the questions incorrectly the computer will explain how the correct answer should be arrived at. Once you have answered 10 questions correctly the practice session will end and you will be able to start the proper test.

A 'key' will be available to you at all times should you need it. This is obtained by pressing the "HELP" key which will be present throughout the test.

The practice sessions are not 'marked' or timed and are just meant to show you how the test works. Read each question and once you've understood it press the reveal button to show your options.......

If you are happy with the explanations and instructions, then click on the button to start the Practice session !

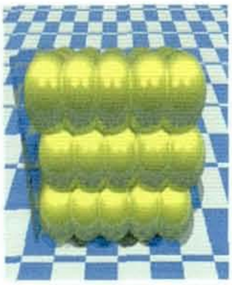
START!

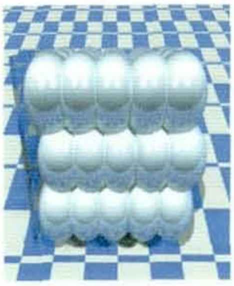
BACK

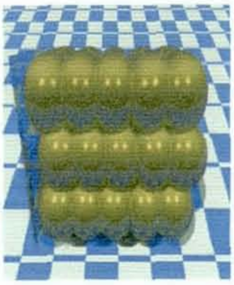
Appendix 9-2

Key Card (Cylinder Condition) – Experiment 6

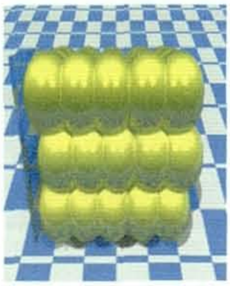
VALUE
Value is shown by the type of metal which the balls are made of: Gold, Silver or Bronze

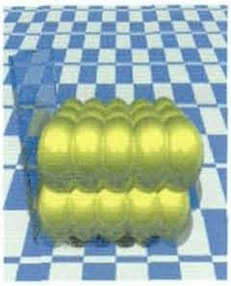

High

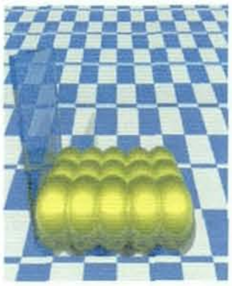

Medium


Low

AVAILABILITY
Availability is shown by the height of the balls against the wall

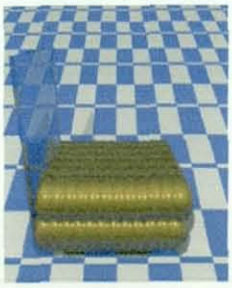

High

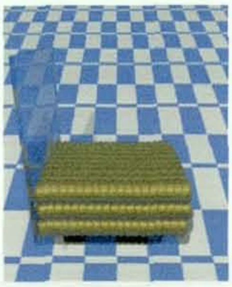

Medium


Low

PACKAGE SIZE
Package Size is shown by the size of the balls


High


Medium


Low

Appendix 9-3

Hypercard Training Stack Script – Experiment 6

```
on openStack
  global i, ii, iii, cardNo, trainbox
  hide menuBar
  put empty into i
  put empty into ii
  put empty into iii
  put empty into cardNo
  put empty into trainbox
  put empty into cd field "array" of card "control card"
  orderise
end openStack

--CLOSE WINDOWS
on x
  global i, ii, iii
  close window i
  close window ii
  close window iii
end x

on e
  global e1, e2
  close window e1
  close window e2
end e

on hideous
  hide button "1"
  hide button "2"
  hide button "3"
  hide button "NONE"
end hideous


-- CREATE an ordered presentation list
on orderise
  put "7" & return into cd field "array" of card "control card"
  put "8" & return after cd field "array" of card "control card"
  put "9" & return after cd field "array" of card "control card"
  put "10" & return after cd field "array" of card "control card"
  put "11" & return after cd field "array" of card "control card"
  put "12" & return after cd field "array" of card "control card"
  put "13" & return after cd field "array" of card "control card"
  put "14" & return after cd field "array" of card "control card"
  put "15" & return after cd field "array" of card "control card"
  put "16" & return after cd field "array" of card "control card"
end orderise


--THE REVEAL BUTTON
on w
```

```
  global i, ii, iii
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put "REV " & the name of this card & tab & tab && elapsedTime &
return after cd field "RecordTime" of card "Results"
  show window i
  show window ii
  show window iii
  show button "1"
  show button "2"
  show button "3"
  show button "none"
end w


-- RIGHT ANSWER
on rightrandom
  global cardNo
  if line 1 of cd field "array" of card "control card" is empty then
    put "38" into CardNo
  else
    put line 1 of cd field "array" of card "control card" into CardNo
    delete line 1 of cd field "array" of card "control card"
  end if
  go card cardNo
end rightrandom


-- WRONG ANSWER
on nextrandom
  global cardNo
  global trainbox
  put cardNo into add10box
  put cardNo into trainbox

  if trainbox < 17 then
    add 20 to trainbox
  else
    add 10 to trainbox
  end if

  if add10box < 17 then
    add 10 to add10box
  else
    subtract 10 from add10box
  end if

  put add10box & return after cd field "array" of card "control card"
  put line 1 of cd field "array" of card "control card" into CardNo
  delete line 1 of cd field "array" of card "control card"
  go card trainbox
end nextrandom
```

```
on joinTest
  global cardno
  go card cardNo
end joinTest

on openCard
  global result
  startRecord
end openCard

on closeCard
  endRecord
end closeCard


//REMOVE close window i, ii, iii

on x
  global i, ii, iii
  close window i
  close window ii
  close window iii
end x


--RECORD the moment the current card is opened
on startRecord
  global startTime
  put the ticks into startTime
end startRecord

on endRecord
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put the name of this card & tab & tab && elapsedTime & return after
cd field "RecordTime" of card "Results"
end endRecord


on saveData
  global Data2


  -- putting the name, time and date into the desktop File name?

  put cd field "subjectId" of card "Intro1" into File2
  put "-Train-" & the date after File2
  open file File2


  -- putting the name, time and accuracy into the saved results File?

  put "TRAINING ANSWERS - Metaphor" && return into Data2
  put the date && the time && return after Data2
```

```
put cd field "subjectId" of card "Intro1" after Data2
put return & return & cd field "Data" of card "Results" after Data2
put return & cd field "RecordTime" of card "Results" after Data2

write Data2 to file File2


--clear the data recording fields for next subject

put empty into result
put empty into cd field "Data" of card "Results"
put empty into cd field "RecordTime" of card "Results"
put empty into cd field "subjectId" of card "Intro1"

go "SectionA"

end saveData
```

Appendix 9-4

HYPERCARD Stack Script – Experiment 6

```
on openStack
  global i, ii, iii, result, cardNo, count
  hide menuBar
  put empty into result
  put empty into i
  put empty into ii
  put empty into iii
  put empty into count
  put empty into mcbox
  put empty into cd field "array" of card "Results"
  put empty into cd field "resbox" of card "rescard"
  randomise
end openStack

-- create a random presentation list
on randomise
  put empty into randomlist
  put the itemDelimiter into delim
  repeat until the number of items in randomlist is 24
    get random of 24
    if (delim&it&delim) is not in (delim&randomList) then
      put it & delim after randomList
      put 26-it & return after cd field "array" of card "Results"
    end if
  end repeat
  delete last char of randomList
end randomise

-- Advance to a random card
on nextRandom
  global cardNo
  global count
  put empty into cd field "countbox"
  put line 1 of cd field "array" of card "Results" into CardNo
  delete line 1 of cd field "array" of card "Results"
  add 1 to count
  go card cardNo
  put count into cd field "countbox"
end nextrandom


-- RIGHT ANSWER
on rightRandom
  global i, ii, iii
  global result
  global cardNo
  global count
  global mcbox
  put empty into cd field "countbox"
  if line 1 of cd field "array" of card "Results" is empty then
    put "27" into CardNo
  else
```

```
    put line 1 of cd field "array" of card "Results" into CardNo
    delete line 1 of cd field "array" of card "Results"
    add 1 to count
  end if
  put the short name of this card & return after cd field "data" of
card "results"
  close window i
  close window ii
  close window iii
  add 1 to result
  go card cardNo
  put count into cd field "countbox"
end rightRandom



-- WRONG ANSWER
on wrongRandom
  global i, ii, iii
  global cardNo
  global count
  global mcbox
  put empty into cd field "countbox"
  if line 1 of cd field "array" of card "Results" is empty then
    put "27" into CardNo
  else
    put line 1 of cd field "array" of card "Results" into CardNo
    delete line 1 of cd field "array" of card "Results"
    add 1 to count
  end if
  put the name of this card && mcbox & return after cd field "data" of
card "results"
  close window i
  close window ii
  close window iii
  go card cardNo
  put count into cd field "countbox"
end wrongRandom



//CLOSE window i, ii, iii, e1, e2
on x
  global i, ii, iii
  close window i
  close window ii
  close window iii
end x

on e
  global e1, e2
  close window e1
  close window e2
end e

--on hideous
-- hide button "1"
```

```
-- hide button "2"
--hide button "3"
--hide button "NONE"
--end hideous

on openCard
  global result
  startRecord
end openCard

on closeCard
  endRecord
end closeCard


-- record the moment the current card is opened
on startRecord
  global startTime
  put the ticks into startTime
end startRecord

on endRecord
  global result
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put the name of this card & tab & tab && elapsedTime & return after
cd field "RecordTime" of card "Results"
end endRecord

-- SHOW WINDOWS & ADD TIME
on w
  global i, ii, iii
  global startTime
  global elapsedTime
  put ((the ticks - startTime)/60) into elapsedTime
  put "REV " & the name of this card & tab & tab && elapsedTime &
return after cd field "RecordTime" of card "Results"
  show window i
  show window ii
  show window iii
  show button "1"
  show button "2"
  show button "3"
  show button "none"
end w

on clear
  global result, count
  put emptu into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Intro1"
  put empty into cd field "resbox" of card "rescard"
  put empty into count
  put empty into cd field "array" of card "Results"
end clear
```

```
-- SAVE DATA ---------------------------------------------------

on saveData
  global Data2


  -- putting the name, time and date into the desktop File name?

  put cd field "subjectId" of card "Intro1" into File2
  put "-SecA-" && the date after File2
  open file File2


  -- putting the name, time and accuracy into the saved results File?

  put "EXPERIMENT 4: Metaphor Condition - Section A" && return into
Data2
  put the date && the time && return after Data2


  put cd field "subjectId" of card "Intro1" after Data2
  put return & return & cd field "Data" of card "Results" after Data2
  put return & cd field "RecordTime" of card "Results" after Data2

  write Data2 to file File2



  --clear the data recording fields for next subject

  put empty into result
  put empty into cd field "Data" of card "Results"
  put empty into cd field "RecordTime" of card "Results"
  put empty into cd field "subjectId" of card "Intro1"
  put empty into cd field "resbox" of card "rescard"



  end saveData
```

Appendix 9-5

HYPERCARD Card Script – Experiment 6

```
on opencard

  hideous

  global i
  global ii
  global iii

  put "G3hH.pict" into i
  put "B3hH.pict" into ii
  put "S3hH.pict" into iii


  picture i, file, rect, false, 8
  picture ii, file, rect, false, 8
  picture iii, file, rect, false, 8


  set the loc of window i to "50, 150"
  set the loc of window ii to "290, 150"
  set the loc of window iii to "530, 150"


end opencard
```

Appendix 9-6

HYPERCARD Button Script – Experiment 6

Correct Answer

```
on mouseUp
  rightRandom
end mouseUp
```

Wrong Answer

```
on mouseUp
  global mcbox
  put the short name of me into mcbox
  wrongRandom
end mouseUp
```

Appendix 9-7

Representations Featuring In Questions– Experiment 6

Key To Representations

1st Letter (G/S/B) = High / Medium / Low *Value*
Number (2/3/6) = High / Medium / Low *Package Size*
2nd Letter (h/m/l) = High / Medium / Low *Availability*

Question	Left Representation	Centre Representation	Right Representation
aA1	S6h	S3m	S3l
aB1	B2l	G3h	S6m
aC1	S3l	B6l	G2m
aD1	S6m	S6l	S6h
aE2	S2m	S2h	S2l
aF2	S2h	G2h	S3h
aG2	G3h	B3h	S3h
aH2	B3l	S2m	G2h
aI3	S2m	G6l	B3h
aJ3	B2m	B2h	B2l
aK3	S3l	G3h	B2h
aL3	G2l	G3m	G6h
aO1	G6l	B6m	S6h
aP1	G2l	S2l	B2h
aQ1	B6l	B3h	B6h
aR1	G3h	S3h	B3h
aS2	G3h	G3l	S3l
aT2	S3l	S3m	S3h
aU2	S2l	G2l	S2m
aV2	S2h	G6l	B3m
aW3	B6l	S3l	G2l
aX3	S6h	G6h	B6h
aY3	G3m	G6m	G2m
aZ3	G3l	B2m	S3l

Question	Left Representation	Centre Representation	Right Representation
bA1	B2m	S3h	G6l
bB1	G3l	B2m	S6h
bC1	S6l	S2l	B3l
bD1	G3l	S3m	B3h
bE2	S3h	S2h	S6l
bF2	G2h	G2l	G2m
bG2	G6l	B3m	S2h
bH2	S3m	G2h	B6l
bI3	S6l	S6h	S6m
bJ3	S2l	B6h	G2l
bK3	G6l	S2m	B3h
bL3	B3l	B3m	B2m
bO1	B3m	B6m	B2m
bP1	S2h	G3m	B6h
bQ1	G3h	B2h	S6h
bR1	G2l	G3l	G6l
bS2	B2m	S3m	B6m
bT2	B2l	B3m	B2h
bU2	G6l	G3l	G2l
bV2	B6h	B2h	B3h
bW3	G6m	G6l	G6h
bX3	S3h	S3m	S3l
bY3	B2l	G3m	S3m
bZ3	S6m	S6h	B6m

Question	Left Representation	Centre Representation	Right Representation
cA1	S3h	S2h	S6h
cB1	B3l	G2m	S6h
cC1	G3l	S3m	B3m
cD1	B2l	B3l	B6l
cE2	G6m	S2l	B2h
cF2	G2m	G2l	S3h
cG2	G3m	G6l	G6h
cH2	G2l	G2m	G2h
cI3	G6l	G6m	G2h
cJ3	S6m	G6m	G6h
cK3	B6h	B6l	B6m
cL3	G6m	S3h	B3l
cO1	G3h	S3h	B3h
cP1	B6l	B3l	B2l
cQ1	G3l	S2m	B6h
cR1	S6m	B3m	G6h
cS2	B3h	G3m	S6l
cT2	B3m	B2m	G6h
cU2	B2m	B2l	B3h
cV2	B6h	B3h	B2h
cW3	B2l	G3l	B6l
cX3	G2l	S3l	B2l
cY3	B2h	B3h	B6h
cZ3	S6m	B2l	G2h

Question	Left Representation	Centre Representation	Right Representation
dA1	B6h	S6l	S6m
dB1	B3m	G3m	S3m
dC1	S6h	S6m	S6l
dD1	B6l	B2l	B3l
dE2	S2l	S2m	S2h
dF2	G6h	G3h	G2h
dG2	B3l	S3m	G2l
dH2	S2h	B2l	S2m
dI3	G3h	S6m	B3l
dJ3	S2h	B6h	G2h
dK3	G2h	G2m	S2l
dL3	B2m	B2l	B2h
dO1	B6h	B2m	B6l
dP1	G3h	G6m	G2l
dQ1	B6l	S3h	G2h
dR1	S2m	B2h	G6l
dS2	S3m	G6h	B2l
dT2	G3m	G2h	G3l
dU2	B2m	G2m	S2m
dV2	B6h	S6h	G6h
dW3	G3l	B2h	B6h
dX3	B2m	G2m	S6h
dY3	S6l	B6m	G6m
dZ3	S2m	G2m	B6m

Appendix 9-8

Questions – Experiment 6

(First letter denotes the part [a, b, c or d] in which the question appeared)
(Number denotes the number [1,2 or 3] of variables the question probes)

Part A

aA1 Which company has the highest value?

aB1 The company 'Rocks Fridges' has just launched on the Stock Market. As yet however the market is still cautious and the shares have a high availability rating. Which of the companies below is it likely to be?

aC1 Do any of the following companies have a high Package-Size?

aD1 Which company has the lowest availability?

aE2 Wino's the pub chain are a company with medium Value and medium availability. Of the companies shown below which is representative of Wino's?

aF2 'Videotica' the pioneering company of Video-on-demand is just about to launch its services using conventional telephone lines. Availability is currently high and it is expected that the company will be a great success. Which of those shown is it?

aG2 Which of the companies below has a low Value and medium Package-Size?

aH2 The conditions of the market are such that the best companies to buy are those with a low Package-size and low availability. Which of the companies shown is most suitable?

aI3 'Digberts', suppliers of dog collars to the Royal Family is a company which has a medium Value, medium availability and low Package-Size. Which of the below is it likely to be?

aJ3 Your ideal company has a high Availability, a low Value and a low Package-Size. Are any of the below suitable?

aK3 Which of the companies shown has a low Package-Size, low Value and high Availability?

aL3 The current market climate demands that low value companies are snapped up as quickly as possible. In addition to this its desirable that the shares are of medium Availability and low Package-Size. Which of the following companies is the most suitable?

aO1 One of the companies below is mid-range in price. Which one?

aP1 TVS the Sports car makers has just launched on the Stock exchange. Currently their shares are rated as being mid-range in terms of number of available. Which of the below is TVS?

aQ1 Shares of Centraco the gas company are rated as medium in terms of purchasing flexibility. Which of the below might be Centraco?

aR1 The household products maker 'Beckitt & Polman' has been judged by the market to have a 'loss of direction'. Shareprices have tumbled to their lowest level ever. Which company is it likely to be?

aS2 The company you are searching for is scarce and can only be bought in large groups. Which should you choose?

aT2 Gill Bates owns the vast majority of the Computer company 'Softicomp' and only a small proportion is freely available on the open market. The shares have then to be bought in medium-sized groups. Which of the companies shown is 'Softicomp' likely to be?

aU2 You are looking for a company which offers a large degree of purchasing flexibility and is expensive. Do any of the below fit the bill?

aV2 'Campico' the tent making company recently had a severe down-turn in profits which is still reflected in the price of the company. There are however only very few shares of this company available on the Stock Market. Which company is it?

aW3 Which of the companies represented below is very cheap, rare and highly inflexible regarding purchasing?

aX3 Ring-a-Ding Phones has just been floated on the Stock Market. Every single one of its shares is available to be bought but in large groups only. The shares are expensive. Which of the below is it?

aY3 Which company is expensive, average in terms of number of shares on the market and has shares which are packaged in medium sized groups?

aZ3 Which of the companies shown below is mid-priced, middle of the range in purchasing flexibility and widely available?

Part B

bA1 The conditions of the market are such that the best companies to buy are those with low Availability. Which of the companies shown below is suitable?

bB1 Which company's shares are grouped in the largest package size?

bC1 Which of the companies below has a high value?

bD1 You are looking for the company with the highest availability of shares. Which is it?

bE2 Which of the companies shown has a low Package-size and medium Value?

bF2 T&A the Clothing company have just had their new range endorsed by Tiffany Beers the Teen Pop Star. Share value of the company is now medium and share availability low. Are any of the below T&A?

bG2 Tiffany Beers the teen pop-star has been especially active lately and has just signed a new contract with Pony Records. Pony's shares have a high Package-Size, and are now high in Value. Which of the below is likely to represent the company?

bH2 'Icypops' the country's largest Ice cream company is rated as medium in value and medium in availability. Which of the below is it?

bI3 The current financial climate means that the optimum choice for your venture into the Stud Farming line of business will be a company which is currently of medium value, high Package-size and high Availability. Which company of those shown below do you choose?

bJ3 The conditions of the market are such that the best companies to buy are those with low Availability, medium Value and low Package-Size. Which if the companies shown below are suitable?

bK3 Which company has a low Value, high Availability and medium Pacakge Size?

bL3 One of the companies shown below has a low value, low Package-size and medium availability. Which one is it?

bO1 'Q Cables' the telecommunications company is just about to be floated on the Stock Market but as yet none of the shares have been sold. Which of the below is 'Q Cables' ?

bP1 The country's leading radio station 'Bland FM' has gone into a state of shock on hearing that the USA's leading Shock Jock has signed a deal with their main rival 'Bland FM' shares therefore go on to hit a record Stock Market low. Is Bland FM below?

bQ1 Which of the companies below is least flexible in terms of purchasing flexibility?

bR1 You are looking to buy a very small number of shares in the Hosiery Industry. The companies below are all Hosiery companies, but one is more suited to your purpose than the others. Which one is it?

bS2 'Pharmaco Drugs' has just announced extremely encouraging profit reports. The price of the company is therefore high, however investors have not yet taken advantage of this and the availability of the shares is still mid-ranged. Which company is it?

bT2 After the disastrous launch of the new toy range 'Make Your Own Spears', shareholders abandon

'Tongo Toys' in droves. Restrictions had never been placed on the number of shares needing to be bought at one time. Which company is it likely to be?

bU2 The company you are searching for is scarce and can only be bought in large groups. Which should you choose?

bV2 Panchester United's shares have always sold in small groups. Now the glory days of the team are at an end and the share value is low. Which of the below is Panchester Utd ?

bW3 'Mulberry' the luxury goods brand has just announced a deal that could boost its sales tenfold in the next year. The price of the company has soared. Availability of the shares is rated as medium, and the shares must be bought in large amounts. Which of the below is it?

bX3 Which of the companies shown below is expensive, medium in rating of purchasing flexibility and has shares which are extremely scarce in the current market?

bY3 'Burtons Biscuits' have had a mediocre year. Consequently their share price is only in the middle range, as is the availability of the company's shares and the groups in which the shares are available. Which company is Burtons?

bZ3 You are looking for the company that offers greatest flexibility in the amount of shares which can be bought, is relatively cheap and has many shares available on the open market. Which is most suitable?

Part C

cA1 Which company has medium availability?

cB1 You are looking for a company with low availability. Are any of the companies below suitable?

cC1 Which company has the highest value?

cD1 The best company for you to invest in at the moment would have a high Package-Size. Are any of the candidates below suitable?

cE2 'Blocks R Us' the Property developer has managed to survive the recent depression and now the company's shares are rated as high in value and low in availability. Which company is it?

cF2 You are on the lookout for companies with a medium availability and small Package-size. Which company would be the most advisable to invest in?

cG2 Which company has a high Value and medium Package-size?

cH2 Chugger Rail the train company has recently acquired new rolling stock and the company share value is now high. The Package-Size of Chugger Rail shares is medium. Which is it?

cI3 'Tearaway Tires' have had an excellent year. Consequently their shares' availability is low and share value is high. The shares have a high Package-Size. Which of the depictions below represent the company?

cJ3 The conditions of the market are such that the best companies to invest in are those with medium Availability, medium Value and high Package-Size. Which of the companies shown below are suitable?

cK3 Bettabuys the Supermarket chain is not doing well and is low in value. Availability of shares is currently medium as is Package-size. Which of the below is it?

cL3 The Bonzai Branch Cutters Company has just been floated on the Stock Market. Share value is currently low as is the availability. The shares currently sell in medium sized amounts. Which of the below is it?

cO1 Terence Toopan the restaurant magnate has just opened another mass eaterie in the trendiest area of the Capital. The market is saturated however and the share value of the company is found only to lie in the middle range. Which of the below is it?

cP1 Which of the companies shown below feature shares which sell in medium amounts?

cQ1 Which of the companies shown below is the least expensive?

cR1 Of the three companies shown below, you wish to choose the one which offers greatest flexibility in terms of the number of shares you can buy in one transaction. Which of the three is most suitable?

cS2 Pokers the Luxury pen producers have just announced annual results which are somewhat disappointing prompting a flood of investors to sell their shares. These are packaged in medium sized groups. Which of the below is most likely to represent Pokers?

cT2 'ZappoGen' has just patented the secret of nuclear fusion. As they will be the only company allowed to produce energy in this revolutionary new manner, the value of the company shoots up.

The company shares are available in large quantities only. Is the company shown here?

cU2 The Luxus Hotel chain has just sold its flagship hotel to its rival in an attempt to prevent bankruptcy. Practically all shareholders are trying to sell their shares. Which of the companies below is it likely to be?

cV2 After the announcement that 'Breakdown Ltd.' is about to go bankrupt, shareholders are falling over each other to get rid of their shares, which have always been available in medium-sized groups . Which of the companies shown below is Breakdown Ltd.?

cW3 Which of the companies shown below is least flexible in terms of shares which can be bought at one time, is highly priced and has very few shares available?

cX3 A curious set of Stock Market conditions means that you are looking for companies offering medium purchasing flexibility which are mid-priced. The shares must be limited in availability. Which company do you choose?

cY3 Which of the companies below is low in price, widely available and highly inflexible in terms of purchasing flexibility?

cZ3 Which of the companies below is cheap, rare and highly flexible regarding amount of shares needing to be purchased?

Part D

dA1 Do any of the companies below have a high value?

dB1 Which of the companies shown below has a medium value?

dC1 Which company has a medium share availability?

dD1 Do any of the companies below have medium Package size?

dE2 Boggalogs the Baking Company has a medium value and high availability. Of the companies below, which is it?

dF2 Nice 'n' Bright paints is about to launch on the Stock Market. Package-size will be high as will availability. Which of the below represents Nice 'n' Bright?

dG2 Which of the companies featured below has both medium availability and medium package size?

dH2 The conditions of the market are such that the best companies to buy are those with a low Package-Size and low Availability. Which of the companies shown below are suitable?

dI3 'Slibbert & Dogsbox' the high-class catering chain are currently a company with a high Value, high Availability and medium Package-size. Which company is it?

dJ3 The conditions of the market are such that the best companies to buy are those with high Availability, medium Value and low Package Size. Which of the companies shown below are suitable?

dK3 'Slibbert & Dogsbox' the high-class catering chain are currently a company with a high Value, high Availability and medium Package-size. Which company is it?

dL3 One of the companies shown below has medium availability, medium Package-size and low value. Which one?

dO1 Elvic the Bottled water company is shocked when it is discovered that the source of their Spring water runs past a Toxic waste dump. Shareholders are all desperate to get rid of their shares. *Which company is it likely to be?*

dP1 Walters the bicycle company is rated as having extremely flexible shares. Which of the following companies is Walters likely to be?

dQ1 Oxaco the Oil exploration company is rated as mid-range in terms of the number of shares on the open market. Which of the below is it?

dR1 'Netserve' the free Internet Service Provider is the first company of its kind onto the Stock Market. The market is unsure of the success of such a venture and the value is cautiously rated as medium. Which of the below is it?

dS2 Rocta Copters the new and wild Helicopter company has not been doing so well recently after the launch of their one rotored Helicopter. Share price is low and the shares are average in terms of the ease with which they can be found on the market. Which is it?

dT2 The share price of News 2000 the media group has hit an all-time low. The shares can also only be bought in large amounts. Which of the below is News 2000?

dU2 Your ideal company is one which is extremely cheap and available only in small groups. Which of the companies below fits the description?

dV2 Air Cymru the world's largest airline is currently rated as medium in price. Shares of the airline are only available in large amounts. Which of the companies shown below is Air Cymru?

dW3 Bumblers Bank has just been declared Bankrupt. The shares are also highly inflexible.Does Bumblers feature here?

dX3 You are looking for a company which offers the highest level possible of purchasing flexibility, is average in terms of the ease with which shares can be found and is expensive. Are any of the companies below suitable?

dY3 Biggleswell the Booksellers is a low-valued company. Traditionally their shares have always been sold in large groups. Today there is a mid-ranged proportion of the company's shares available. Which company is Biggleswell?

dZ3 You are looking for the company that offers low flexibility in the amount of shares which can be bought, is mid-priced and is predominantly privately owned. Which company do you choose?